PLASTIC AND RECONSTRUCTIVE SURGERY

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CHAPTER III

TRANSPLANTATION OF SKIN, DERMA, AND MUCOSA

The clinical experiences on which this chapter is based now embrace a period of a decade and a half. The experimental work carried on from time to time was suggested by the obvious discrepancies in the results attained, as additional clinical experience was gained. It soon became evident that many of the advantageous properties, provided a good "take" could be obtained, became increasingly maximal, the thicker the applied skin graft had been cut; and, on the contrary, the disadvantageous properties, save that of a certainty of a "take," increased as the skin was cut at a more superficial level. This suggested the need of attaining a skin graft cut at such a level that most of the good qualities of the thin graft and the thick graft would be embraced, while the disadvantageous qualities of each would be minimized. This more or less ideal skin graft was visualized as a graft of uniform thickness cut in the last quarter thickness of the skin. In other words, clinical observations seemed to indicate that this skin graft probably would be such a graft that successful transplantation would be almost assured, and yet the thickness would be such that adequate protection and minimum contraction would be attained, and, at the same time, the match with the surrounding skin would be relatively satisfactory in so far as texture and color were concerned. Moreover, the donor site would be left in such a condition that it would be capable of spontaneous regeneration.

Unfortunately, the mechanical means for removing such a skin graft had not as yet been developed. It was necessary, therefore, to invent a mechanical device capable of cutting such a graft. This took some eight years of more or less desultory experimentation. As additional experience was gained the experimental work carried on from time to time was suggested by the obvious discrepancies in the results attained.

Soon after it was possible to cut this new deep intermediate skin graft, it became evident that not only was this skin graft proving to have the advantages predicted for it, but that skin grafts cut with the dermatome at other thicknesses had advantages over skin grafts cut by other methods. These were due largely to the fact that one could vary the thickness of the skin graft at will, remove skin in quantities with a uniformity and facility not possible previously, and obtain skin from parts of the body which could not be used as donor sites with former methods.

After the study and calibration, as to the thickness by means of comparative crosscut microscopic sections of a considerable number of skin grafts, cut by all methods, from individuals of different ages, sex and race, it seemed that the whole matter of skin grafts should be reclassified from the standpoint of thickness.

These new developments have not only extended the general indications for skin grafting but appear to have limited what was formerly thought to be indications for the use of pedicled flaps.

As some surgeons still insist on attempting to transplant homogenous skin, the practicability of such transplantation was also studied.

Historical

A brief resumé of some of the landmarks in the development of any phase of surgery is usually interesting, and may aid in gaining a certain judicial perspective.

Centuries ago, in old records concerning the tilemaker's caste in India, a description is recorded of the free transplantation of full thickness skin from the gluteal region to the nose. Previous to transplantation the gluteal region was beaten, producing hyperemia. For

the purpose of advertising an ointment, early in the nineteenth century two charlatans, one of whom was a woman, Gamba Curta, cut a piece of skin from their bodies, passed it around to spectators for inspection, then replaced the pieces on their original raw bed and applied their ointment as a dressing. It is related that the grafts "took" and healed with little scarring. Baronio (1804), a physiologist, aroused by the knowledge of this exhibition, experimented on a sheep's tail and successfully transplanted full thickness skin from one side to the other.

As early as 1823, Bunger of Marbury successfully transplanted a free piece of whole skin from a woman's thigh to her nose; and again in 1843, J. Warren Mason, one of the famous surgeons of Boston, successfully covered the alae of the nose with a bit of detached full thickness skin from the arm.

It was not until after Reverdin published an exhaustive paper in 1872, under the title of "Epidermic Graft," that the interest of the surgical profession was aroused. The transplanted bits were composed of the whole epidermis and a very little of the dermis. Reverdin's bits of skin measured 0.3 to 0.4 centimeters square. His method hastened healing but it was soon noted that, especially in the region of the joints, this method of grafting did not prevent contracture. Knowledge of the work of Reverdin caused Ollier to experiment with larger areas of skin 4.6 by 8 centimeters square. He used the epidermis and a portion of the dermis. Ollier apparently was not trying to produce multiple centers of epidermization, as had Reverdin, but to produce a complete epithelial surface by means of skin grafts. At the time Ollier's work was not particularly noticed or appreciated. In 1874 Thiersch transplanted skin pieces 1 centimeter in diameter, from which the adipose tissue had been carefully removed. In his report in 1886, he demonstrated that the healing of wounds of any size could be brought about quickly by covering the defects with large films of epidermis together with a small portion of the dermis. Up until 1890 this graft was placed upon the ulcer surface. But that year Halsted showed a case in which he had excised the ulcer and the graft had been placed upon the fresh fibrotic base. The Ollier-Thiersch method did not entirely prevent contractures, and resistance to mechanical insult was limited.

Netolitchi of Germany (1869), Lawson of London (1871), and LeFort of France (1872) undoubtedly preceded Wolfe of Edinburgh in 1875, in the successful transplantation of whole skin. Wolfe, whose name along with that of Krause of Germany, has been associated with this particular type of skin grafting, used the method for ectropion of the eyelid. The following year, Krause (1876) reported 21 cases at the twenty-second German Surgical Congress. Now the grafts are often designated as Wolfe-Krause grafts.

Thus, although isolated records of an occasional success are found here and there in the literature many years previous to the articles of Krause, the significance of the method was not appreciated. Even these men, and, of course, those preceding them, used only small bits of skin. A method for successfully transplanting large areas—6 by 10 inches—was not developed until after World War I. It remained for Blair, Davis, Brown and Padgett to be particularly active in developing the technique of growing these larger areas of full thickness skin.

In the recent past, one of the five types of skin grafts has been used in the majority of instances. The small graft introduced by Reverdin in 1869 has always been used by some operators. Davis within the past quarter century has been responsible for popularizing the small deep graft for use on large granulating surfaces. The Ollier-Thiersch graft, first performed by Ollier in 1872 and later modified and developed by Thiersch from 1874 to 1876, has been used very commonly by many surgeons. More recently a modification of the Ollier-Thiersch graft, the "split graft" of Blair and Brown has found great favor. For the purpose of covering an asceptic denuded surface, the full thickness graft has been used with considerable success, especially since the development of a more accurate technique.

Several modifications of the method of application of the basic types of skin grafts were developed during World War I or shortly after. Among these were the so-called "inlay" stent graft introduced by Esser in 1917, and the "outlay" stent graft, a modification of the Esser principle, introduced by Waldron, Gillies and Pickerill in 1918.

Another method of grafting skin that has some utility is tunnel grafting. MacLennan in 1912 and Moszkowicz in 1916 and 1917 described tunnel grafting with thin skin. Parce in 1922 employed full thickness skin to form a tunnel. In this method, after the graft has "taken" in its subcutaneous or subgranulation tunnel, the superimposed tissue was removed. Among others, Keller (1930) has advocated the method after using it for ten years. The advantage claimed for the method is that a clean field for the graft is assured. The "sieve" graft, described by Douglas in 1930, is another method of applying a full thickness graft. Small interspersed areas of skin may be left in the donor area by this method. Dragstedt (1937) recently has described a graft somewhat similar to that of Douglas.

Among the less commonly used methods of skin grafting is the method of implantation of small bits of thin skin into or beneath the granulation tissue. Pollock in 1870 devised this method, and in 1920 Braun revived it. More recently (1930) Wangensteen has used the method. The method is of value when the granulation cannot be cleaned up. A modification of this method is that described by Westhues in 1926. He advised that the skin be woven in and out of granulation tissue by means of a needle. Among the rarely used methods that have been suggested are those of von Mangoldt, who in 1895 applied pulpified epidermis to a denuded surface, and Lusk, who in 1879 advocated and used a vesicating agent to cause a blister, and then utilized the elevated skin as a graft. Glasser and Richlein have more recently used a similar "scrape method."

Iso or Homografts

The earlier operators made attempts to graft from one individual to another, but in the second half of the last century Ollier and Thiersch observed that autotransplants of skin were most often successful. According to Loeb, it was recognized at that time that different species and different individuals might differ in their chemical constitutions. A review of the literature of homotransplantation of skin reveals a surprising disagreement in findings.

Lexer, Freeman, Perthes, Holman and Blair have only failures to report with isodermic grafts. On the contrary, Davis, who based his statements of the feasibility of the procedure on hospital records by interns, vouches for the practical value of the procedure. Mason recommended for success the same procedure of obtaining a donor, as for a successful blood transfusion, but in his report nothing is said about the length of time the cases were observed. Shawan, also, attests to the success of the procedure when a proper blood-matched donor is used. A great many other less authentic reports can be culled from the literature, the authors of which apparently thought they had had some success with homografting of skin. Usually, the length of time these grafts were observed is not tabulated. In all probability, this is the reason for what we believe must have been misobservations.

Importance of Homotransplantation to the Basic Sciences

Transplantation of tissues, originally developed to repair surfaces denuded of skin, has in recent years assumed great experimental importance. The biologist and embryologist have used the procedure to determine the extent to which development takes place by self-determination in contradistinction to inconstant environmental factors. The physiologist has used the method to determine the function of organs and their specific excretions. Growth phenomena, the origin of specific cells and the relation of normal growth to tumor growth has been studied by the biologist and pathologist. Among the geneticists, Correus has attempted to correlate the data of genetics with that of transplantation.

Recently the great importance of the relative nearness of the relationship between the

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host and the transplant, as the principal factor that determines the fate of the graft, has been recognized in its full significance. Loeb found that in skin transplantation from animal to animal, the length of time the graft remains viable depends upon the amount of leukocytic and fibroblastic reaction shown by the host against the graft, and the intensity of the reaction depends upon the nearness of the blood relationship of the donor to the recipient. More recently, in the human, Loeb's findings have been substantiated by a series of experimental skin transplants (forty-four in number) performed by Padgett.

Histological Changes in Homografts

Brown and McDowell have taken biopsies following homografting, and they have noted that in 10 to 11 weeks following operation, the grafts begin to disappear. Early in this process, the biopsies show interstitial edema with slight cellular infiltration as might be seen in an urticarial wheel. Later, the interstitial edema is less striking, and the cellular infiltration becomes heavy, consisting chiefly of round cells with many eosinophiles and some polymorphonuclear cells. This heavy cellular infiltration coincides with the disappearance of the various dermal elements and epithelium in scattered areas. It would appear that the proteins in the homograft are antigenic and that the host requires about 3 weeks to build up a maximal allergic response to them. If a second crop is applied to the patient at this time, a failure to take would be expected. Brown and McDowell advocate the use of homografts as emergency dressings for the immediate treatment of burn cases, noting again that epithelization of the recipient's own skin is stimulated and that the grafts disappear at the third week, leaving clean granulations.

Blood Groups and Homotransplantation of Skin

It has been suggested and maintained by Davis, Mason and Shawan that the result of homografting of skin depends upon whether or not the red blood cells of the donor are agglutinated by serum of the host. According to the theoretical considerations previously outlined, the improbability that the blood group of donor and host can be of particular significance is evident. Blood groups probably depend upon a few genes and tend to throw all individuals into four groups; while the individuality or organismal differential most likely is determined by all, or, at least a great number of genes of an individual. Thus, the theory of organismal differentials multiplies the possibilities of strangeness to an infinite number.

Most likely, certain chemical characteristics, which were designated by Loeb as the individual differentials, are present in most tissue and are common to a given species. Similarly, the tissues of near relatives of different strain, varieties, species, genera, and classes of animals have in common certain chemical characteristics. The tissues of the host assume injurious properties, and toxins are thrown out which destroy the grafts. These differentials determine the degree of intensity of reactions between host and donor.

Experimental work has shown that the substances thrown off by the graft do not act in the nature of antigens, and do not call forth the production by the host of secondary (immune) substances which cause the graft to be destroyed. If secondary (immune) reactions were important, it might be expected that the homo-reaction following a second transplantation would appear more promptly but no acceleration of time seems to occur. The evidence seems to indicate that individual differentials in homotransplantation are the result of primary substances given off by the grafts, which substances act as toxins and stimulate the cells of the host to a leukocytic and fibroblastic cellular reaction against the graft.

The hypothesis that these differentials are genetically determined is suggested by the whole series of gradations in reactions found on transplanting tissues into strange hosts. The individual differentials are more closely related within the same family, species, or strain. Consequently, grafts of skin from brother to brother or sister to brother (close

syngenesic-transplantation) remain viable the longest after transplantation.

A slight decrease in the length of time that the graft remains viable is noted in the care of transplantation of parent to child (a more distant type of syngenesio-transplantation). Experiments in closely inbred animals show similar varying reactions according to the nearness or distance in relationship of the donor and the host. Thus, we conclude that organismal differentials are genetically determined.

Apparently the organismal differentials depend upon the totality of genes which make up the chromosomes which are present in the cells of the host and donor. Presumably the genes, or more specifically gene derivatives, determine the character of the differentials. The Y chromosomes must have little to do with reaction, as it makes little difference whether host or donor are of the same sex.

Summary

Briefly, the result to be expected after isodermic skin transplantation may be summarized as follows: An immediate "take" occurs in the majority of cases. In non-related individuals, between the second and the third week, the grafts begin to disappear and by the end of the fourth week have completely disappeared. On individuals related by blood (syngenesic-transplantation), such as father to son or even uncle to nephew, the graft "takes" and remains viable about three weeks, but by the end of the fifth week it is destroyed. In identical twin transplantation (the closest possible syngenesic—or near relation transplantation), the grafts have remained in situ in 4 cases over 1 year, and it is assumed that such grafts may take permanently. Successful transplantation of skin from one identical twin to another was first reported by Padgett in 1932 and again by Brown in 1937.

At the present time, the evidence—both experimental and clinical—is sufficient to justify the following brief conclusions: (a) Autotransplantation of skin usually succeeds; (b) Syngenesic-transplantation of skin is theoretically improbable except in identical twins, where it is theoretically probable and clinically has occurred; (c) The failure of experimental isodermic grafts to remain viable on the human and animals and theoretical reasoning argue against the blood group of the individual as playing a role of any essential significance in homotransplantation of skin; (d) *And finally, the bulk of experimental and clinical experience is in agreement that iso or homotransplantation of skin is not practicable, except possibly in identical twins.*

Heterografts and Zoografts

Although successful transplantations of animal to the human have been reported by Baratoux, Dubousquet, Laborderie, Cannaday, Rivin, Browning, Flegenheimer, Venable and Miles, the results of the present day experimental work would lead one to think that undoubtedly there must have been some mistake in interpretation. Zoografts disappear even more quickly than homografts. Leo Loeb, as previously mentioned, has painstakingly investigated this question. He found when, instead of tissue to another animal of the same species and variety, the tissue is transplanted to another variety (as white to hooded rats), the result is essentially the same as after homotransplantation, but the fibroblastic and the lymphocytic reaction is more marked, and by the twentieth day the transplant is destroyed.

As previously noted, when syngenesic-transplantation (between brother and sister or parent and child) is done, and the relative relationship is diminished to the utmost nearness of that of autotransplantation, the behavior of the host towards the transplant is similar to that of autotransplantation for about five weeks. After this period of time disharmonies between the host and the transplant develop, the transplant is invaded by lymphocytes, and eventually overwhelmed. Finally, if instead of transplanting tissue within the same species, it is transplanted from one species to another (heterotransplantation), the immediate direct injury to the transplant by the body fluids of the host is so great that marked degenerative changes are shown at the end of the first week. Not only lymphocytes

but also polymorphonuclear leucocytes collect about the transplant, and it is destroyed rather quickly.

Parabiosis

Of interest in passing, is the unique experiment of uniting two animals of the same species by a surgical operation. This was performed by Bert and Sauerbruch and Heyde. Recently Gillies attempted to transfer a skin flap from one individual to another three times and failed. Gillies has reported a case of a baby joined to its mother's thigh by a direct skin flap for four weeks before division. Although apparently a complete surgical "take" and every process of repair was present when the pedicle was divided, the whole flap sloughed off in 24 hours. Section across the scar showed loops of blood vessels approaching either side of the scar, which he intended to demonstrate that there was total incompatibility between the two blood systems. Parabiosis seems not to improve the chances of transplantation of skin. The innate virility of one or the other of the animals eventually overcomes the less virile animal, and its vitality is sapped progressively until death. Even at a time when both are in good health, skin transplanted from one partner to the other does not grow so well as previously, and surprising as it may seem, even transplantation of skin from one part of the animal's body to another part (autotransplantation) shows a decrease in the tendency to thrive.

Wilhelm Reinhard and Alfred Lauer working in Germany, flapped a fourteen-year-old sister with a traumatic loss of tissue, to her brother. The flap apparently took, and on the 6th day the patient and donor were both quite well. At that time prontosil was administered to the flap recipient and was recovered from the urine of the donor. On the eighth postoperative day the patient was slightly jaundiced judged by the sclera. At that time morphine and sleeping tablets administered orally to one of the attached was transmitted to the other. However, late on the eighth postoperative day the recipient suddenly went into absolute collapse. She vomited, became extremely pale and chilled despite a slight temperature elevation (38 C). She became pulseless and her haemoglobin fell to 40 but the blood picture showed no morphological changes. The donor suffered no ill effects. She was given intravenous therapy but the next morning her haemoglobin was 30 per cent and her condition even more serious. Clinically the flap looked to be satisfactory. However, the clinician felt it necessary to transect the flap and following a transfusion the recipient made a nice recovery. These workers typing the patient on the ninth postoperative day discovered that the recipient was a type A and the donor type 0 and on this basis judged the ill effects to be due primarily to incompatibility of the blood groups.

Stephenson and Padgett, working with litter mates and odd dogs that were carefully cross-matched as to blood group noted that some of the dogs died of acute pulmonary edema on the third day. If they did not die they usually spontaneously separated by the twenty-first. There was a fall in hemoglobin up to the third day and likewise a rapid sedimentation rate on the third day. This gradually righted itself, becoming normal by about the twelfth and fifteenth day following the cross-flapping. They also observed that if the first dog was not separated from the second within a short time following the death of the first dog, the second dog expired equally rapidly. By injecting Evans blue dye into one of the dogs and drawing hourly blood samples thereafter from both dogs, they established the fact that there is circulatory communication by the third postoperative day—and that about the tenth day following the cross flapping procedure there has ceased to be circulatory exchange. The total and fractional protein, cholesterol, as well as the chloride values show little alteration by such intercommunication. The qualitative protein change and chemical changes of the tissue at the site of flapping is being investigated.

Transplantation of Fetal Membranes

In 1909 and 1910 Davis experimented with amniotic sac but was unable to secure permanent results. In 1913 Sabella and Stern re-

ported several cases in which they had successfully transplanted amniotic membrane. Since that time others have failed to obtain permanent results.

Metaplasia

Brown and McDowell state that metaplasia of skin grafts or flaps does not take place. The skin of each area is specialized and retains its characteristics when transplanted. Skin grafts to normal mucous membrane surfaces show no evidence of any change to mucous membrane, according to their biopsies and studies.

Rehn and Uihelin studied cutis grafts following transplantation and believe that the tissue undergoes a gradual metaplasia, assuming the appearance and function of the tissue surrounding it. Peer and Paddock substantiated these findings, and Cannaday presents supportive evidence. These changes we have never been able to substantiate.

Preservation of Skin Grafts

Rarely can an indication for the preservation of skin exist, since the evidence indicates that successes with fresh homografts, not to mention heterografts, do not occur. However, Carrel in 1912, after preservation of skin in warm petrolatum followed by soaking in warm Ringer's solution for periods varying from 24 hours to 7 weeks, gained the impression that skin, preserved for as long as 2 weeks, grafted as well as normal skin, but after that period successes were not to be anticipated. It would appear that one might question this observation, as Carrel's transplants were homografts. Present day experience leads one to believe that homografts do not remain viable even when applied immediately, much less after preservation for 2 weeks. It would seem probable, however, that tissue cultures of autogenous epithelium should grow after an indefinite length of time.

Recently Davis (J. S.) has stated that he has preserved autogeneous deep skin grafts for several days in saline gauze in the ice box, and in vaseline in the ice box for a week or two, after which the grafts "took," when they were applied to a granulating surface. It would seem from this observation that one need not be in any great hurry to transplant autogeneous skin, if it is carefully preserved. We are of the opinion that, as a rule, the quicker the skin is transplanted, the better. We have, also, observed that if one places a skin graft in saline solution and washed out the serum from the endothelial space, the graft is less likely to "take" than if it has been placed in gauze dampened with saline, which does not wash out the blood serum.

In 1930, Kubanyi reported, autoplastic grafts remain viable if preserved in the serum of the individual. Brown and McDowell report using a skin graft 48 hours after removal. The refrigeration of skin grafts has been investigated both experimentally and clinically. Briggs and Losi Jund skin-grafted mice 3-5 weeks of age. They report that the graft remained viable after slow freezing to 78 C. and followed by rapid thawing. Fifty-two per cent of the grafts took wholly or in part. Autoplastic skin stored at 0 C. for 5 days failed to take. Clinically, Webster has studied refrigerated grafts which he has applied to 23 patients with skin grafting in 36 procedures. Four of these were full thickness, and 5 grafts were homogenous and refrigerated for less than 21 days. Of the autogenous grafts, some were preserved 4 months before transplantation. The author experimented both with rapid freezing and lypholized grafts. The former were all lost, but the lypholized grafts he reported to be successful in 80 per cent of the cases. The use of refrigerated grafts in cases where the granulating area is ready for grafts at the time the skin is obtained and in such cases where an excess of skin has been removed and can later be utilized in the event the "take" is not 100 per cent" are suggested by the author.

AUTOGRAFTS OF SKIN

Histology

Early in our experience, a microscopic study of a series of skin grafts at various periods after application (Fig. 19) was made. Particular attention was paid to the fate of the elastic

fibers in the graft. A skin graft tends to present a shiny appearance. The thought arose that this might be due to the fact that the elastic fibers degenerated, and were not replaced, so that the normal corrugations of the skin remained obliterated. However, we came to the conclusion that the elastic fibers did reappear, but not in the orderly manner which is characteristic of normal skin. Although the ultimate disorderly arrangement of the elastic fibers may have something to do with the tendency to a glistening appearance of a skin graft, it is more likely that it is the replaced cicatricial tissue, which tends to obliterate the normal surface corrugations in the epithelium of the graft.

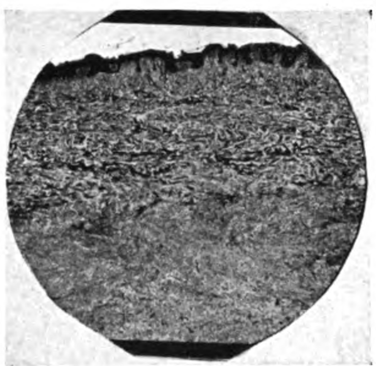


Fig. 19. Section of a three quarter thickness skin graft taken from the abdomen and applied to the forehead. The skin had been in its new location for 15 days. The tissue was strained by Verhoeff's method for the demonstration of elastic tissue fibers. These can be made out vividly in the corium. Here they are represented by the dark black appearing interlacing fibers. No special reduction in normal content is noted.

After autotransplantation of skin, the repair is somewhat analogous to that of the repair of an ordinary incised wound. The graft is first fixed in place by an exudate of fibrin. Within about 5 hours after transplantation, the graft becomes adherent to its base. The fibrin layer is soon infiltrated by leukocytes and phagocytes. A primary stage of plastic circulation, which varies from 24 to 48 hours, temporarily preserves the viability of the graft. Soon the endothelium of the blood vessels of the host send proliferating buds toward the graft and into the graft. Some of the endothelial buds seem to connect with the endothelial spaces of the graft. The endothelial spaces of the graft that do not connect up with endothelial sprouts from the host show degenerative changes. The new formed vessels developing in the fibrin layer, arise mainly by papillary budding of the endothelium.

Davis and Traut, for instance, have noted that if the endothelial spaces of the graft are collapsed, interference with the nutrition occurs. The stage of vascularization begins at about 18 hours and from then on is progressive. Injection experiments have demonstrated vessels in epidermis grafts on the second day and in cutis grafts on the third day. Within 65 to 70 hours definite continuity of the blood vessels of the host and those in the central part of the graft can be noted. Garre was of the opinion that the vessels had largely resumed their function by the third day. Thus, early plasma imbibition appears to play an important role in the nourishment of the graft. Later success depends upon the early development of an adequate circulation of the blood. About the fourth or fifth day, the stage of organic union begins, when the layer of fibrin and leukocytes begin to be infiltrated with sprouting fibroblasts. These penetrate and connect up with the fibroblastic elements of the graft. By the eighth day the blood supply is nearly complete. Now grossly the graft appears distinctly pink. By the tenth day the fibroblastic connection is fairly firm and complete. This is the connective tissue, which accounts for the subsequent contraction of the graft.

A question of considerable interest is the amount of degenerative change that takes place in the graft coincident with the proliferative changes just described. Early some of the endothelial cells of the graft show degenerative changes, but proliferative changes largely overshadow the picture. The most superficial layers of the epithelium tend to show some degenerative changes. Some exfoliation is likely to occur. The degree of exfoliation is in direct proportion to the speed of the revascularization of the graft. Within the epithelium, the infiltration of round cells is often quite marked. In the middle layer of the

graft a certain amount of degenerative changes are seen in both the fibroblasts and the elastic fibers, especially the latter, and considerable infiltration with leukocytes is noted. The degree of infiltration is somewhat variable, and seems to depend upon the thickness of the graft and the rapidity of its vascularization. On the whole, most of the fibroblasts seem to remain viable, and the regenerative picture of replacement with new granulation tissue overshadows the degenerative changes. The elastic fibers degenerate and are replaced by fibrous tissue, which appears to be derived from pre-existing elements of the graft itself. The process of degeneration of the elastic fibers is rather slow. For a considerable length of time no change is shown. Regeneration of the elastic fibers occurs and is more or less complete within one and one-quarter to one-half years after the graft has been transplanted; but never again are the elastic fibers arranged in so orderly a manner as they are in normal skin.

Briefly, some degenerative changes go on coincidently with rapid regenerative changes, and probably a good share of the cells of the graft retain their viability. At least, if they are replaced, the replacement must take place over a long period of time and is not readily discernible. The epithelium regenerates most rapidly. Later the sub-epithelial tissues regenerate and replace the granulation tissue, which is converted into fibrous tissue derived from the host.

Thus, the histologic examination does not establish complete viability. Viability is most complete in the juxta-epithelial layer of the graft. The histologic picture of the full thickness graft does not differ materially from that of thinner grafts. The process of degeneration and regeneration is slightly more rapid in thinner grafts. Before 7 days a thin graft presents rather complete regeneration and replacement of the epithelium, but in full thickness grafts, one can still find degenerative masses in the epithelium considerably later than this.

Most of the sweat glands placed centrally in the graft show some degenerative changes, which are soon followed by proliferative changes. The hair follicles change in a similar way. The histologic evidence of the manner in which nerves regenerate in skin grafts is meager. Practically the only data available is of a clinical nature. Kadanoff transplanted skin from the sole to the snout in guinea pigs. He was able to find new nerve fibers more numerous than was normal for the foot. They frequently followed the old paths of the blood vessels. No regenerating Pacinian corpuscles were found, nor did he find degenerative changes in the sensory endings immediately after transplantation of the graft.

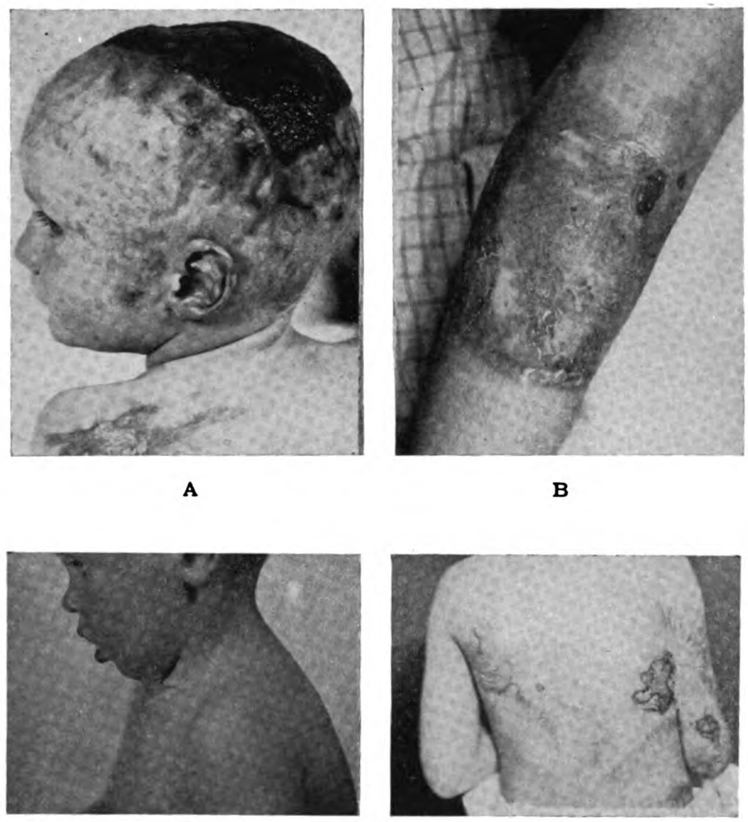
Within 2 to 3 months a layer of fat begins to develop beneath the graft, the cellular infiltration disappears, and the fibrous tissue layer decreases in width and amount. The fibroblasts begin to lengthen. The skin then gradually becomes movable and pliable on its base.

The Objectives To Be Attained

Observation leads one to believe that often resurfacing is attempted with a relatively hazy idea of the real objective to be attained. To produce a relatively good result within a minimum time the surgeon should have a clear cut idea of the problem in hand and the shortcomings of the material available.

Often the surgeon fails to appreciate adequately the amount of original epithelial destruction that has occurred, when he observes or attempts to resurface a granulating wound. If the epithelial destruction has been complete, the wound must close by epithelium coming in from the periphery or by fibrous tissue drawing the bed together. Most commonly, wounds are closed by both growth processes.

The anatomy of the part, very largely determines the method of closure (Fig. 20). Thus, when the denuded area is over the side of the ribs or in the middle of the thigh, where the bony structures are strong and the soft tissues only moderately yielding, a greater part of the closure of a wound is made by the scarred epithelium which grows in from the circumference according to the natural rapidity of



A B C D

Fig. 20. (A) A burn which if allowed to scar over without aid will be forced by the underlying anatomy to close principally by epithelization from the circumference. (B) A burn which because of the anatomy of the region has closed principally by epithelization from the circumference. (C) A burn which has closed principally by the contracture of the fibrotic base. (D) A burn which over the ribs will close principally by epithelization from the circumference and, in the axilla, principally by contractural fibrosis.

epithelial growth. On the other hand, when the destruction of soft tissues is located in front or back of a joint, which can be restricted in its normal radius of movement, the greater part of the wound closes by contractural fibrosis, depending somewhat on whether the limiting scar is within or without the angle of movement. Naturally, the larger the original surface destruction, the greater is the tendency to contracture and limitation of flexion or extension. In some instances, an additional factor is added by the density and contractile pull of an innate tendency to the formation of a keloidal scar. Splints and correct position will not limit this tendency as scar tissue acts like a rubber band. The contractural tendency is distinctly one of its properties. The only remedy, if one is to prevent the formation of a healed contracture, is early and complete resurfacing of the wound with a sheet of skin as thick as one dares to use on a granulating surface.

The inexperienced surgeon very often misjudges the amount of original epithelial loss when he attempts to correct a surface scar or a healed cicatricial contracture. The extent of the destruction of epithelium is the amount the wound will gap after all contracting scar has been removed or crosscut and the region placed in overcorrection. To give permanent correction, one must resurface the denuded area with a skin graft or skin flap of sufficient size to cover the denuded area.

Properties and Technique of Removal of the Skin Grafts Used Before the Development of the Deep Intermediate Skin Grafts

Broadly speaking, insofar as the thickness of the skin graft is concerned, the reconstructive surgeon in the past has had only two types of free skin grafts with which to repair the various defects that he encountered when a free skin graft was indicated: (1) the thin Thiersch or the somewhat thicker "split" graft removed by knife or razor from some such area as the thigh, and (2) a thick graft (the full thickness skin graft) which was commonly removed from the abdomen.

Our experience with these grafts up to January 1, 1938, when for reasons to be enumerated later, we began in most cases to use grafts as cut with the dermatome, was as follows: A total of 755 separate areas had been covered in 563 separate operations on 456 individuals. Of these areas grafted, 386 were grafted by means of the Thiersch or "split" type of graft, and 369 areas were covered by the full thickness skin graft. 145 of the areas covered were granulating and 610 were aseptic denuded surfaces. The 369 areas covered with full thickness skin were all placed on aseptic denuded surfaces. Since January 1, 1938 a full thickness skin graft has occasionally been used for the correction of web fingers or small cicatricial contractures of the fingers in children; and sometimes when a granulating area was small and in an inconspicuous place, a "split" graft has been used as a matter of saving time.

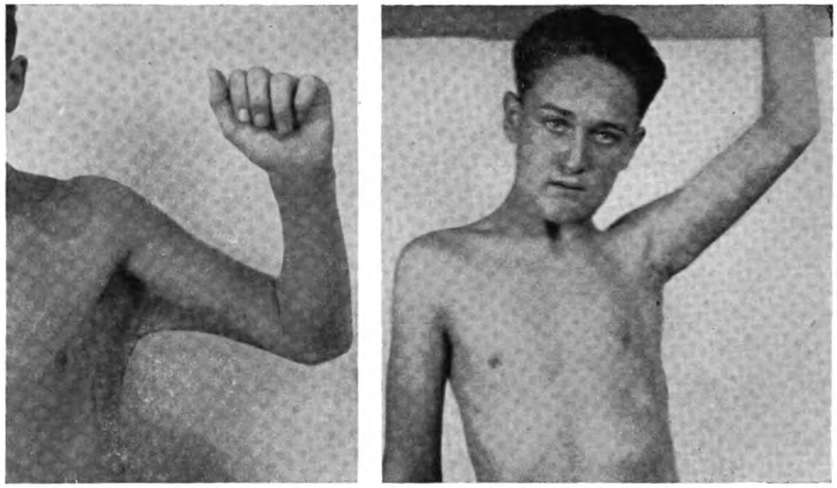
At least three properties of skin grafts are very much dependent upon their relative thickness or thinness. First, the base on which the skin lies tends to contract in proportion more or less to the relating thinness of the skin graft which is applied. When a skin graft is placed on a freshly denuded aseptic surface with a movable base such as the anterior neck, a thin graft may contract as much as 60 per cent. However, if a thin graft is laid upon freshly denuded scar or derma, periosteum or bare bone, or on areas surrounded by tense skin or scar, the subsequent contraction may be quite minimal. Second, the final appearance tends away from that of normal skin more or less proportionate to the relative thinness of the graft. That is, a full thickness skin graft most nearly approaches the normal skin in appearance. Third, on an aseptic denuded surface the hazard of not obtaining a "take" or only a partial "take" will run from one-eighth to one-third greater, varying somewhat according to the location on which the application of the graft is made when a full thickness skin graft in contradistinction to a thinner type of skin graft is used. If a full thickness skin graft is applied to a granulating surface, it is seldom that a "take" is obtained.

Properties of the Thiersch and "Split" Grafts

The Thiersch graft is a thinner graft than the true "split" graft. However, the two grafts fall into a group which has a certain similarity in so far as their properties are concerned.

Among the advantageous properties of the thinner types of skin grafts are the following: (Fig. 21). Grafts of this type of large size can be obtained easily with relatively little damage to the area from which they are cut. A "take" is almost certain. If correctly used on surfaces where weight bearing or repeated trauma are not factors, such a graft may give sufficient protection. The time of healing does not depend upon the size of the graft. As a general rule, the operation can be done quickly. The donor area heals rapidly from the base and one can retake the newly formed skin after three or four weeks if necessary. The postoperative dressing period is short—from ten days to two weeks.

A sufficient amount of "split" graft will correct cicatricial contractures of such areas as the axilla, the elbow region and the popliteal space. Thus, the correct application of the thinner type of grafts sometimes offers a method which, in one or two operations, will correct functionally a considerable contractural deformity, or adequately cover a raw area of considerable size. Thinner grafts are the grafts of choice on a fresh granulating surface and often on hidden clean raw surfaces which will resist contracture. Upon the sub-



A B

Fig. 21. This is an example, before and 3 months after operation, of a rather severe contracture of the axilla which was corrected by means of cross-cutting, removing the scar, and applying a graft as thick as could be cut with the large knife. (Padgett, *Surg., Gynec. & Obst.*, 1939, *69*:779.)

cuticular muscles of the face, the orbicularis oris, and the orbicularis palpebrum, the thinner types of grafts have been, in most cases, the grafts of choice. Also, for cavity grafting the thinner types of grafts are usually chosen. That is, for the situations and lesions mentioned, the thinner types of grafts are chosen because of the comparative simplicity of their application and the greater certainty of their "take." Among the main disadvantages of the thinner types of grafts, one may state that the appearance is not very good, there is considerable contraction and the protection may not be sufficient.

Technique of Cutting a Thiersch or "Split" Graft

The technique developed by Blair and Brown, we believe, is the most satisfactory technique that has been presented for the cutting of a Thiersch or "split" graft (Fig. 22). When the graft is cut, the skin is held tense and flat by traction pressure of small straight edged flat pans held on either side of the knife. The knife used by Blair and Brown is 18 centimeters long and 2 centimeters wide. It is made of a strip of razor steel set in a stiff back. The knife is light. It can be stropped on a piece of canvas but will have to be ground occasionally. To a somewhat lesser advantage in respect to size, one may use an ordinary straight edge barber's razor instead of the knife just described. The heel and toe should be rounded and sharpened so as not to hang in the skin while being used.

The suction retractors used by Blair and Brown are hollow brass boxes with the underneath side open. The rim that contacts the skin is beveled. Boxes of three different lengths of openings may be obtained—4.5, 7 and 9.5 centimeters—for the application to areas of different sizes. Just within the opening there is a series of transverse bars which prevent the skin from being drawn in toto up into the box. The tube leads from the top of the box to be connected to a noncollapsible rubber tube which is in turn connected to a strong suction machine. There is a string valve on the top of the box with a screw for the adjustment of the strength suction. The suction usually used is a half of an atmosphere of negative pressure.

With such a suction retractor one is able to cut much more quickly and to make grafts larger and of more uniform thickness and to cut them within certain limits of varying thick-

ness—all of which widens the field of usefulness of these grafts. Although not particularly necessary, a very thin film of vaseline may be applied to the donor site. The suction retractor is drawn slowly along the surface just ahead of the knife neither raising nor depressing the skin. The fundamental idea in the cutting of the graft is to get an area which is flat,—which is on tension, and which is immobilized so that the knife cuts uniformly. If muscles are on tension beneath the area from which the graft is cut, a raised place is likely to cause one to cut through the derma and into the subcutaneous fat. The leg, therefore, has to be placed in a position so that underlying structures are not on tension.

Ordinarily, the skin is taken from some part of the inner thigh or the upper outer thigh. These grafts are cut thick enough so that if a new growth of hair on the graft is not desirable they should be cut from a non-hairy surface. In young babies the abdomen may be the site of choice. Considerable difficulty, however, will be experienced in cutting a graft of fair size from the abdomen of a baby as it is difficult to cut a good "split" graft from a baby or a young child because the skin is so thin. This difficulty may be encountered in certain regions on women. If possible, the graft should be large enough to cover the whole area and even to extend beyond the edges. If this cannot be done, the fewer the grafts that one has to cut to gain this end, the better. On a large thigh with a fair amount of subcutaneous fat, good sized grafts of fairly even thickness can be cut with a long light razor ground knife.

Marcks has devised an attachment for the Blair knife for the purpose of calibrating skin grafts. We have had no experience with the use of this recently devised appliance.

Properties of a Full Thickness Skin Graft

Among the disadvantageous properties of the full thickness skin graft one may enumerate the following. On granulating surfaces, the probability of a good "take" is too slight to make its use of much practical value and even on an aseptic denuded surface on an average, one runs about a 20 per cent chance of losing variable portions of the graft. Some superficial loss from blistering is often a feature. Depending upon the depth, this may endanger the final appearance. Less often focal areas of necrosis will be present. These may

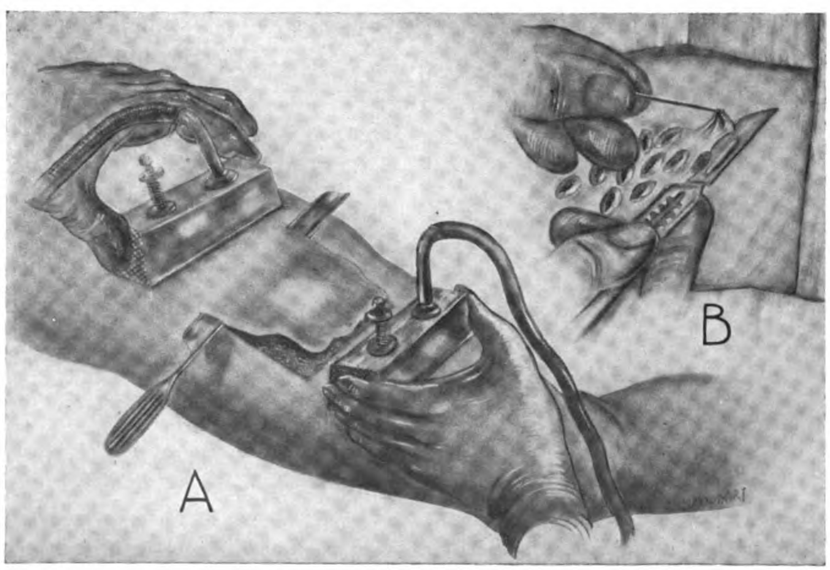


Fig. 22. (A) Method of cutting a "split" graft from the inner thigh. The knife and suction boxes shown are those originated by Blair. One can also cut a Thiersch graft in this manner very well. (B) Method of Davis for cutting small deep grafts.

not only compromise the final appearance but also, depending upon their number and size, may jeopardize the functional result. It is particularly difficult to get a full thickness skin graft to "take" in its entirety on an aseptic denuded surface which is concave or has a great deal of unevenness.

On a concave surface with a rounded firm base, a good "take" will usually occur. Characteristically, particularly if there be considerable blistering and areas of focal necrosis, the postoperative dressing period is prolonged over a period of from three to five weeks. Finally, it is necessary to draw together and suture the skin edges of the defect after the removal of a full thickness graft. In contrast, on the face, the neck, on the palm of the hand, over the dorsum of the hand including the knuckles, a full thickness graft is indicated. A full thickness graft tends to develop a more plentiful subcutaneous tissue than the thinner graft.

To offset the disadvantages of a full thickness skin graft, one can enumerate the outstanding advantages which follow the application of a full thickness graft. After a perfect "take" of a full thickness skin graft, the appearance will more nearly approach that of normal skin than that following the application of any other type of skin graft. The amount of subsequent contraction is minimal for the group of skin grafts as a whole (Fig. 23). A full thickness skin graft will give the greatest protection possible to be obtained by the application of a free skin transplant (Fig. 24).

Likewise, on the face, the neck, the palm of the hand, over the dorsum of the hand including the knuckles, or between the fingers, if the "take" of a full thickness graft is good, the final result both as to function and appearance is the best that can be obtained.

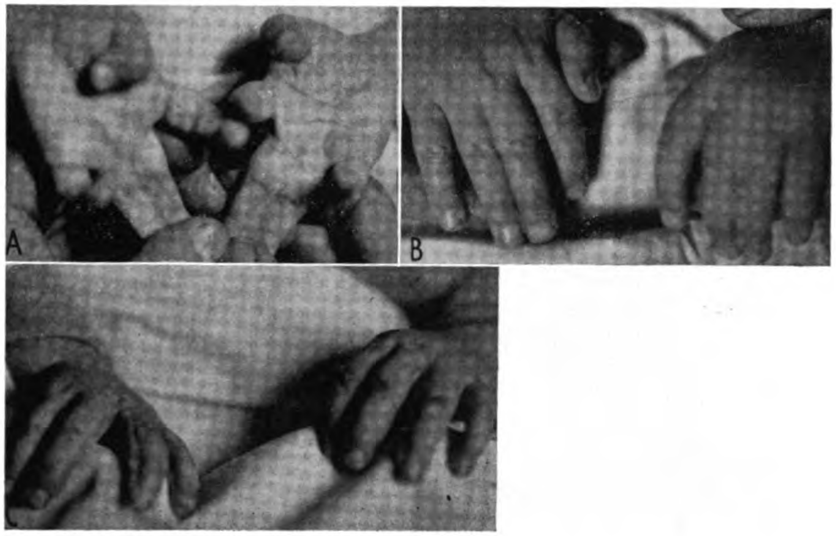
Technique of Full Thickness Skin Grafting

In planning the operation one should take into consideration that the graft will contract about one-fourth and open up the scarred tissue completely, overcorrecting the deformity as much as possible. In situations such as the neck, the axilla and the fingers, the maximum amount of extension is obtained by cutting across or excising all scar tissue bands that are put on tension by overcorrection.

If the grafting is to be done on account of scar contractures, they are laid wide open without regard to the size of the resulting raw surface, provided that the denuded surface is

A B

Fig. 23. Severe burn of chin which pulled lower lip into a position of ectropion. Considerable scarring of upper lip and sides of cheek does not show very clearly in the photograph. (B) Scars were completely excised and a full thickness skin graft was applied to the upper lip, the sides of each cheek and beneath the lower lip. A graft 6 by 2 inches was applied beneath the chin. This was necessary for complete relaxation. The face has assumed normal appearance and the lips normal position.



C

Fig. 24. Complete webbing between the second and third fingers of both hands. (A) Ventral view. (B) Dorsal view. (C) The fingers about 2 months after correction by the application of full-thickness skin grafts between the fingers. The webbing was corrected in one operation by this method. (Padgett, *Surg., Gynec. & Obst.*, 1939, *69*:779.)

not of such extent as to jeopardize the life of the patient, and that enough skin to cover the area can be obtained.

A raw fairly flat surface having been obtained, the skin is cut by pattern from the abdomen, the back, or the thigh, in such a manner that no subcutaneous fat remains. The line of incision is on the level of the base of the corium. As one cuts with the scalpel the skin must be kept on tension. One will find that if Kelly clamps are placed close together at the edges, tension may be kept on the skin by means of traction (Fig. 25). If one rolls the skin graft over a gauze roll held in the fingers of the left hand, this will aid in giving a slightly convex surface at the line of incision. Webster has recommended a special roller for this purpose which is of considerable aid. With practice, one can accomplish the same thing with a wad or roll of gauze as with the special roller. After the graft is removed, the wound caused by its removal is closed with superficial and deep sutures, if possible. When this is not possible, the wound is preferably covered with a thin graft to lessen the time of healing that would otherwise follow if the wound has to heal by secondary intention.

Special Types of Skin Grafts

Small Deep Skin Grafts

The small skin graft of Reverdin (1869) probably was not as deep as the small deep graft introduced by Davis in 1914. The graft of Davis is a conical piece of skin comprising the entire thickness of the corium in the central portion, and tapering off toward the periphery to include the upper layers of the epidermis. With a reasonable assurance of a "take," they may be laid directly on intact granulations if some care has been taken in preparing the surface. The graft may be cut from the thigh, the abdomen, or from almost any area of the body, and a large number of these grafts can be obtained from a relatively small area, thus making it possible to use these grafts on extensive wounds without severely taxing an ill patient. They are fairly easy to remove under local anesthesia. The application of a small deep graft is a simple method of skin grafting and, because a "take" will usually occur on a granulating area even if it is not scrupulously clean, the small deep skin graft has achieved some popularity with certain surgeons (Fig. 22B).

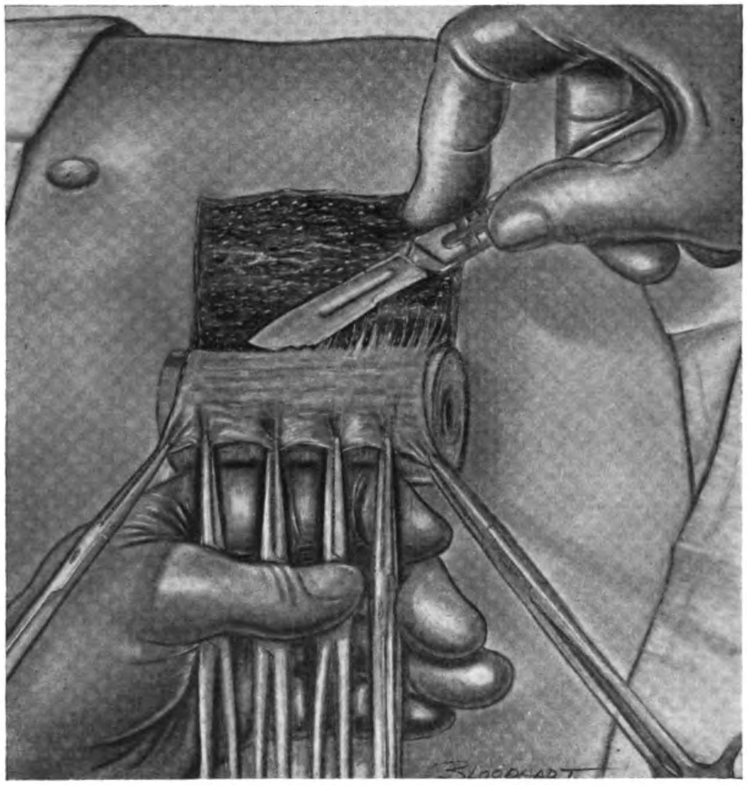


Fig. 25. Technique of removing a full-thickness skin graft from the abdomen. Clamps are placed on the edge and later one may place one on each side for tension. A sharp knife is used for cutting. One cuts in the corium in such a manner that no fat or blood vessels are left on the graft. A roll of gauze may be used or a special roller to hold the skin as flat as possible and to help give the proper tension.

This graft has some disadvantages. First, from the functional standpoint, the base on which they are placed shows a rather marked tendency to contracture due to the interspersed scar and also due to this fact, the area on which the graft is placed may not become soft and pliable but rather thick and keloidal. As a permanent covering they are not of great value on flexor or extensor surfaces. On cosmetic grounds, an objection to their use in certain locations is due to their tendency to pigmentary changes and the interspersed heavy scar formation.

Finally, sometimes there is a marked desquamation of the grafted area when it dries out, especially between the grafts, which is evidently due to epithelial over-production. This scaliness, however, usually can be controlled by the application of an emollient. Davis (J. S.) has used the small deep graft with excellent results on clean granulating areas, and many of his students have been rather partial to the advantages of this graft. It was probably because early we became impressed with the advantages of a large thin sheet of skin that we have selected it, as a rule, when aiming to resurface a large granulating area. There are, however, certain chronic ulcerations, which are extremely difficult to get clean enough so that a sheet graft will "take." The small deep graft has been of value in obtaining re-epithelization in such situations. It sometimes can be used to advantage to cover certain wounds, when it is necessary that the patient be ambulatory.

Technique: Agnew first suggested the simplest method of raising a small graft. The technique recommended by Davis is similar. A bit of epidermis is picked up with a straight needle held with an artery clamp (Fig. 22B).

The skin is raised so that a little cone is formed and the base of the cone is cut through by depressing the blade of the knife. The graft, still on the needle, is transferred to the wound with the raw surface downward. These grafts vary in size from about 1/12 to 1/6 of an inch in diameter, but usually should be placed on the wound just about as close together as possible. Davis recommends that a dry sterile rubber protector be placed over the graft. This serves to press the graft out somewhat more flatly. The protective rubber tissue is cut into strips so as not to impede any secretion that may drain from the wound. Next, strips of gauze wet in some antiseptic solution are placed over the protective strips of rubber. Davis, also states that paraffined mosquito netting directly over the graft followed by a layer of boric acid ointment is useful. The paraffin netting gives immobilization.

"Sieve" Graft

In 1930, B. Douglas described a skin graft which he termed the "sieve" graft. The graft, as applied to the recipient site, is essentially a full thickness skin graft with multiple interspersed holes. The skin which would have been in the graft if not for the holes, is left in the donor area for the purpose of regeneration. Before the graft is removed the holes are cut with a special cutting punch. In principle it is a modification of the small deep graft of Davis.

This sieve graft undoubtedly has certain advantages which lend to it some recommendation. The fact that the donor area heals without suture is a definite advantage. The fact that the drainage is good is another point in its favor. But to apply a full thickness skin graft to a granulating surface no matter how perfect the drainage, may prove to be somewhat hazardous procedure. On an aseptic denuded surface one does not need so much drainage as this graft allows, provided good hemotasis, a proper dressing and good fixation are obtained.

This graft violates what seems to me to be a fundamental principle in an ideal skin grafting operation in that the total area is not covered with epithelium. A certain percentage of the grafted area must be covered by scar which tends to contract, thus to interfere with pliability and to some extent, in certain situations at least, to decrease its ability to withstand wear and tear. We have no doubt that by the use of this graft some excellent results may be obtained but in the past we have felt that in most cases, the selection of either a "split" graft or a full thickness graft came nearer to fulfilling the requirements of the situation in hand. Now a deep intermediate graft of proper thickness would seem to be the preferable graft.

The Implantation Method of Skin Grafting

The advantage of the implantation method of skin grafting is that it can be used in certain cases in which commonly practiced methods of skin grafting will fail. The only condition that must be fulfilled is that granulation tissue must be present. Wangensteen, for example, has been successful in obtaining a "take" with this type of skin graft with feces from a colostomy being discharged over the wound; and, also, in a large unclean pressure sore with considerable undermining of the skin located over the ischeal tuberosities as following thigh amputation for arterio-sclerotic gangrene. The method may be useful in ambulatory patients. The indication for the method, in general, is in those cases in which other methods fail.

About eight days after implantation, the grafts make their appearance as whitish areas. These rapidly increase in size and new skin gradually covers the granulations. The final epithelial layer may be little better than a scar, may break down under trauma, and is prone to become somewhat keloidal.

Technique: The technique is simple. The skin is removed, as for a Thiersch graft, and cut into 2 to 4 millimeter squares. With the blunt end of a needle each square of skin, after implantment, is pushed obliquely into the granulation tissue, until the graft disappears from sight. As the needle is withdrawn, the graft is held in place with a tissue

forceps. The granulating surface is seeded with grafts about 1 centimeter apart.

Alglave has used the implantation method of skin grafting, but made small excavations in the granulations with a small curette before placing a fragment of skin in each.

Tunnel and Buried Skin Grafts

Neither the buried or tunnel skin graft represents a different type of skin graft, but unique technics of application. The principle is a modification of the Esser inlay graft.

In tunnel grafting the skin is introduced beneath the surface. After the buried graft has taken, the overlying tissue is cut through to expose the grafted area. This graft has been used by Keller for both the release of contracture and for insertion beneath a granulating ulcer. The graft has two advantages: it is not likely to become infected and it more or less immobilizes itself. The graft has been stated to be applicable where a full thickness graft is desirable, but cannot be employed because of an infected base. An example would be a chronic ulcer over a weight bearing surface. The graft can be used to correct contractures over depressions and folds of the body such as the axilla, where the application of pressure and immobilization may be difficult. A series of grafts are buried at right angles to the contractures and held in place by overlying subcutaneous or granulation tissue.

In our series of cases, preference was given to simply covering a granulating area, the removal of an old ulcer, or crosscutting and removal of a contracture, after which a sheet skin graft was applied with a dressing to gain pressure and immobilization.

Smith has recently achieved some quite good results by undermining such lesions as flat scars, moles, and moderate sized birth marks, after which he inserts a sheet of full thickness skin over the denuded bed. The wound of insertion is closed. After about ten days the superimposed skin is excised and the edges of the skin graft and the surrounding skin are coated with sutures. He claims that his percentage of good "takes" is superior to those obtained with a full thickness skin graft applied directly to a denuded surface. He also states that one can get a "take" even if some fat is left on the graft. If this is true, it is contrary to the ideas of most men who have had a large experience with skin grafts of different thicknesses. Also, another question is brought to the front, namely, what rôle does heat and moisture or tissue plasma play in the matter? The place of this method of applying a skin graft is as yet unknown. If the contentions of Smith are true, this technique of applying a full thickness skin graft holds considerable promise.

Pulpified Epidermis

Von Mangoldt has applied scrapings of epithelium, blood and serum from the donor area to a granulating surface. In Pels-Leusden's Clinic these scrapings were injected into the granulation tissue with a syringe. Also, Reschke has injected epithelial scrapings beneath an ulcer.

Although we have never used either of these procedures, by analogy, we surmise that the procedures have little to recommend them. It would seem to us that the purposes for which one applied a skin graft could not be fulfilled by the use of these methods. Even though healing by epithelization was obtained, the scar would most likely be excessive. As indicated, other methods used should be more effective.

Superficial and Deep Calibrated Intermediate Skin Grafts and the "Three Quarter" Thickness Skin Grafts

About a decade ago Blair and Brown, in an effort to combine the advantageous qualities of the thin razor graft with that of the full thickness graft, presented a skin graft alleged to transect the uppermost 25 to 75 per cent of the skin. This graft they designated as the "split" skin graft. It represented a definite step forward. However, we were never able to cut the graft without considerable variation as to thickness and size.

It occurred to us, after observing the advantages of the "split" graft, that if one could cut a uniform graft at a level below that suggested

by Blair and Brown, and yet keep above the lower limits of the corium, such as graft would have desirable qualities not yet obtainable. For many purposes the ideal graft should be directed towards obtaining a graft of such thinness as to assure successful transplantation, leave the donor site capable of spontaneous regeneration and yet be of such thickness as to afford adequate protection, minimum contraction, and at the same time, match the surrounding skin relatively satisfactorily in so far as texture and color are concerned.

Furthermore, to be able to vary the thickness of the graft at will would permit the selection of various thicknesses of skin desired by the surgeon for the correction of different lesions in different parts of the body. Again, according to the age of the patient and the particular region from which the skin was to be removed, a variation in thickness might be desirable, as it is well-known that the skin of children is thinner than that of adults, and that the skin in certain regions varies, as, for instance, the skin on the inner thigh of a woman is thinner than that of the outer thigh. Moreover, for certain lesions it is evident that if one could remove the skin from any area of the body, such as the chest, the back, or over the ribs, certain areas could be resurfaced in a way not possible by the use of the methods commonly employed.

But to cut a graft such as I had in mind, entailed mechanical problems. The ordinary skin graft knife was found to be inadequate. Aside from the difficulties encountered in its application in relation to anatomical location, age, and sex, the most formidable objection was the inability to cut a uniform sheet of skin at a predetermined level with any mechanical precision.

*The Dermatome**

With these ideas in mind, it occurred to me that if one could draw the skin to a smooth surface and hold it in some manner, it could be cut in a sheet of uniform thickness, and of a thickness previously decided upon, by passing the knife through the skin at a definite distance from the surface—truly an accurately calibrated dermatome. In 1930 I carried this conception to a Professor Hood, a mechanical engineer at the University of Kansas, and enlisted his aid to see if I could overcome the mechanical difficulties of the problem. From 1930 to 1937 in a more or less desultory fashion, several different mechanisms were discussed, constructed, tried out and discarded, as not being workable or practical. Finally, fastening the skin to a smooth surface with a cement or adhesive so that the skin would be held firmly to a longitudinally level surface while being cut was tried. A mechanism consisting principally of a drum with a movable knife fixed at a definite distance from the drum was constructed. It was found that it was possible, with the greatest facility, to remove a sheet of skin as large as the drum (4½ x 8 inches) (Fig. 26) or smaller, and to cut it absolutely uniform in thickness, and that the thickness could be varied as described by turning a calibrated mechanism which regulates at will in a predetermined fashion the distance of the knife from the drum. Furthermore, it was found that the graft could be cut to pattern by painting out the area not to be removed with a solution and thus nullify the adhesive properties of the cement and thus prevent the adherence of the skin to the drum in this area. In 1938 the final model was worked out which, although embodying the fundamental idea of bringing the skin to a smooth surface, contained several very definite improvements which have facilitated the use of the machine (Fig. 27).

Varying Thickness: In an adult when the main indication is one of resurfacing a granulating area, usually the graft is cut from .010 of an inch (.25 mm.) to .014 of an inch (.36 mm.) in thickness (Fig. 28-32). When a clean raw surface is to be covered in an adult, and the indication is one where the appearance is a prime factor, or it is essential to have minimal contracture, the grafts are ordinarily cut from .022 of an inch (.56 mm.) to .024 of an inch (.60 mm.).* It was found that at this

* The Dermatome is sold and manufactured by the Kansas City Assemblage Company, 609 East 17th Street, Kansas City, Mo.

* When it is desired to be absolutely accurate in percentage depth, it is well to incise the skin vertical to its surface to judge the thickness of the skin before setting the calibrating mechanism of the dermatome.

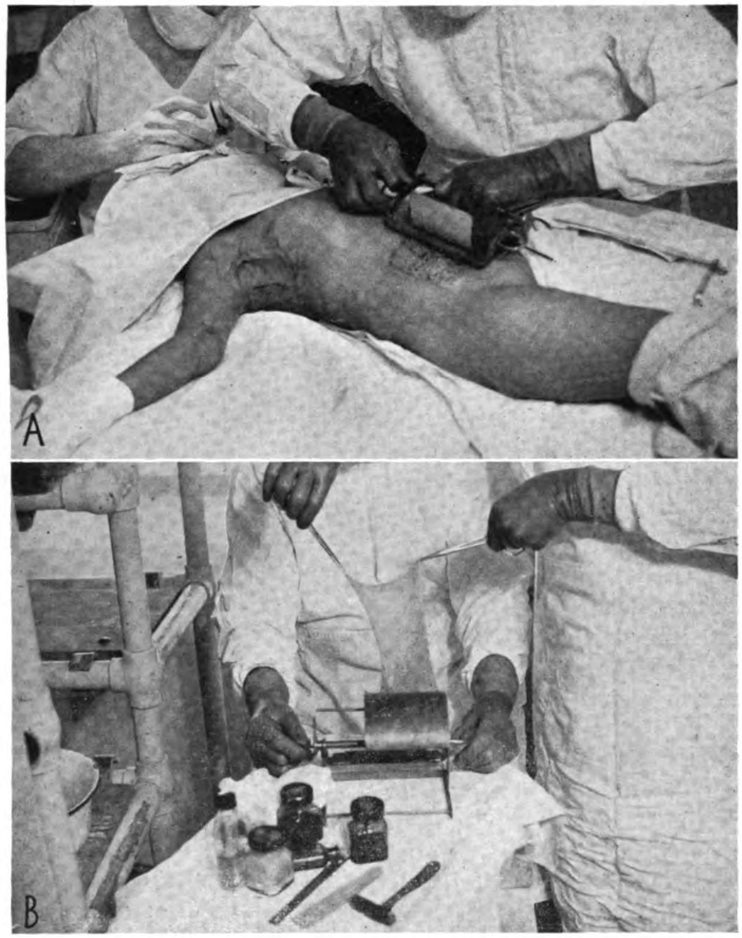


Fig. 26. Adhesive cement is applied to both the drum and the skin. (A) The machine is shown working along cutting the skin from the abdomen in a perfect sheet. This skin graft is to be used to correct the axillary contracture shown in the photograph. (B) The sheet of skin is being pulled away from the drum with hemostats. It will be noted that the sheet is the same size as the drum and that it is a perfect rectangular shape of uniform thickness. (Padgett, *Surg., Gynec. & Obst.*, 1939, *69*:779.)

thickness, a sufficient amount of subepithelial elements remained to the base for early regeneration. When maximum appearance or minimum contracture were not such clear cut indications, and the certainty of "take" seemed to rank relatively high in the balancing of essential factors, the grafts usually were cut between .016 of an inch (.41 mm.) to .020 of an inch (.5 mm.) in thickness. Observations were made on the thickness of the skin in varying locations in both sexes. In a woman, particularly after repeated pregnancies, if the skin over the abdomen, the inner thigh or the inner upper arm is removed at a level of .018 of an inch (.46 mm.) to .020 of an inch (.5 mm.), all of the subepithelial elements will be removed. The variation in the thickness of the skin in diverse locations changed in the male, but not to as great an extent as in the female.

Coincidently, while making these observations on the thickness of adult skin, children were being operated upon and their skin thickness was checked. In a young child (for instance, 6 years of age), if one cuts a graft from the abdomen of as little thickness as .014 of an inch (.36 mm.) to .016 of an inch (.4 mm.), one may remove all of the subepithelial elements of the skin and healing will be by

secondary intention. When a calibrated graft is removed from a baby 2 or 3 months old, in order to leave sufficient epithelial elements in the bed for regeneration the graft should not be cut more than .010 of an inch (.25 mm.) to .012 of an inch (.3 mm.) in thickness. When the child is about 12 to 14 years of age, one cannot cut lower than .016 of an inch (.41 mm.) to possibly .018 of an inch (.46 mm.) in thickness, if he wishes to leave subepithelial elements.

For purposes of study, a Thiersch graft, split graft cut in the routine manner, and a full thickness graft cut with a scalpel, were removed from the patient at the time of cutting a calibrated skin graft. About one-hundred sections were obtained from varying ages. After fixation these were carefully cross-sectioned at nearly right angles to the skin surface, and their relative thickness compared with the known thickness of the calibrated skin grafts.

Classification

From this microscopic study of skin grafts cut by all methods, a re-classification of sheet skin grafts into four types seemed to us to be indicated: (1) Thiersch*; (2) Superficial Intermediate (Blair et al) 1/3 to 1/2 of the skin depth; (3) The new Three Quarter Thickness Skin Graft (75 to 90 per cent of the skin depth); and (4) The Full Thickness.

The measurements made by us are as follows: (1) The Thiersch graft is cut at a thick-

* Thiersch's original description of his graft as containing only the epithelial layer probably never was or can be cut. There is always some corium.

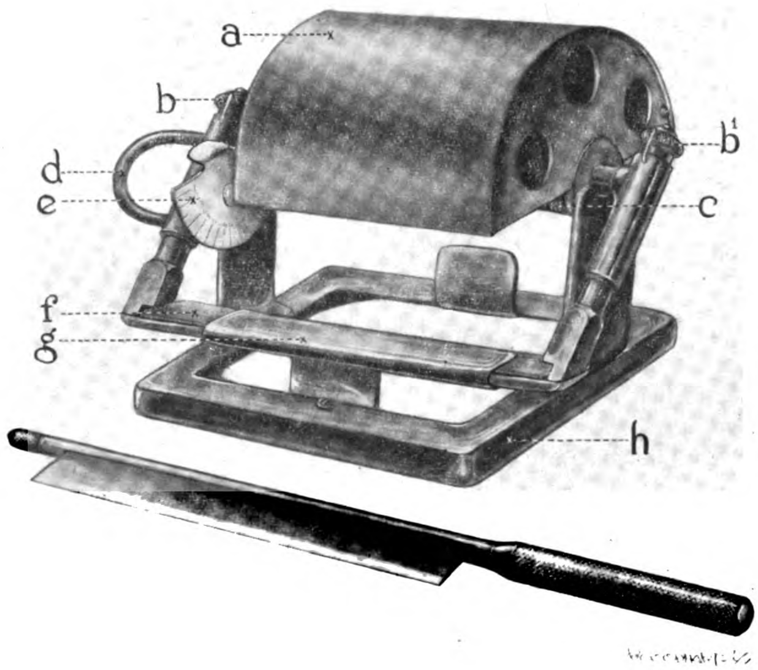


Fig. 27. Drawing of dermatome on stand. a. Semicircular drum. c. Hand holder to rotate the drum (left hand). b and b¹. Calibrated screws (.002 inch between lines on screw head) which allow bilateral adjustment of distance of knife from the drum. d. Ring to finger to motivate the knife holder (right finger). f. Knife blade. g. Slide to hold knife blade in position. h. Base of stand to hold drum. e. Calibrated dial (.002 of an inch between lines) attached to eccentrically placed central shaft which passes through the handle of the drum and allows the distance of the knife from the drum to be adjusted unilaterally. By proper setting in conjunction with the screws b and b¹ the danger of the knife being jammed into the drum is eliminated. Lower drawing shows handle to hold knife when honing or to use when cutting a skin graft by hand.

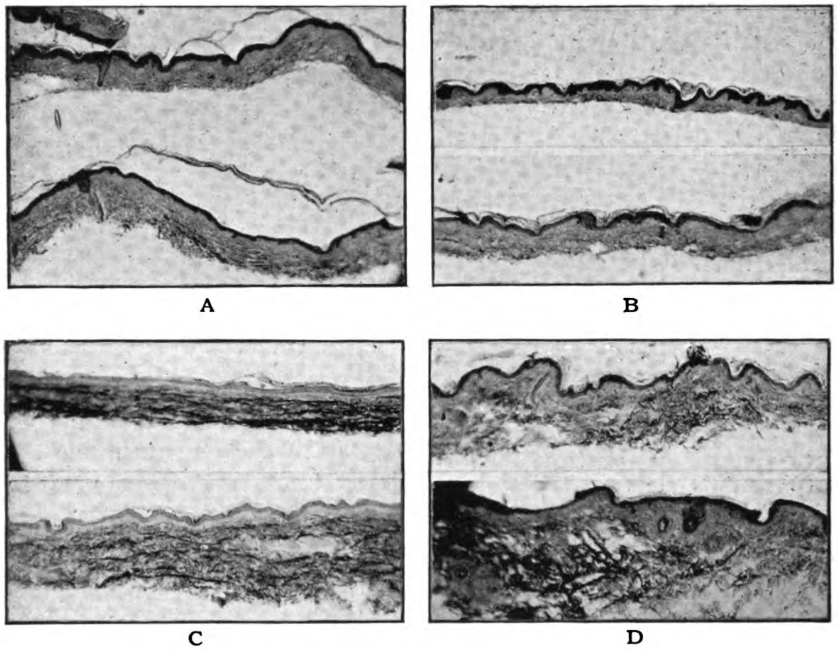


Fig. 28. (A and B) Sections of Thiersch skin grafts. (C and D) Sections of split skin grafts showing variation in thickness. ×16. (A) Thiersch graft cut from outer thick adult male about .010 of an inch in thickness (.25 millimeter). (B) Upper section: Thiersch graft cut from outer thigh of male, age 8 years, about .007 of an inch in thickness (.18 millimeter). Lower section: Thiersch graft cut from outer thigh of male, about .010 of an inch in thickness (.25 millimeter). (C) Split graft cut from outer thigh of adult male shows variation from .010 of an inch (upper) (.25 millimeter) to .014 of an inch (lower) (.46 millimeter) in thickness; same graft. (D) Split graft cut from outer thigh of adult male shows variation from .010 of an inch (.25 millimeter) to .018 of an inch (.46 millimeter) in thickness; same graft. (Padgett, *Surg., Gynec. & Obst.*, 1939, *69*:779.)

ness of about .008 of an inch (.2 mm.) to 0.10 of an inch (.25 mm.) in thickness (Fig. 28) (2) The "split" graft or superficial intermediate skin graft, as cut with the large knife, is usually from .012 of an inch (.3 mm.) to .018 of an inch (.46 mm.) (Fig. 28-29). (3) The new "Three Quarter Thickness" Skin Graft, which is cut with the dermatome and may be predetermined, is from .022 of an inch (.6 mm.) to .026 of an inch (.66 mm.) in thickness (Fig. 32). (4) A full thickness skin graft in an adult, according to our sections, varies in thickness from about .032 of an inch (.8 mm.) to .040 of an inch (1.0 mm.)* (Fig. 31).

* Skin contracts quite markedly after it is cut, due to the elastic fibers in the corium. These figures are for the skin before it contracts. After it contracts and is stained and placed on a microscopic slide it will measure nearly twice as great in thickness. For example, a section cut with the knife set at about .032 of an inch (.81 mm.) away from the drum will measure in width about .060 of an inch (1.5 mm.) on the slide. In the photomicrographs the skin was cross-cut as nearly at right angles as possible. A considerable number of each were taken—about one hundred different sections in all. An average was struck to compensate for error on sectioning. The examples shown are more or less average and considered fairly typical. The photomicrographs were enlarged 22 times above the size of the tissue on the slide.

Any and all of these grafts obviously can be cut more proficiently with the dermatome than by any previous method. These experiments were done solely to determine what we had been doing in the past.

Superficial Intermediate Calibrated Skin Grafts as Cut with the Dermatome

There is no essential difference between the superficial intermediate calibrated skin graft as cut with the dermatome and that cut by other methods. No new factor is involved except that one may select a predetermined thickness and cut the graft with the dermatome at a uniform depth which cannot be done by means of the large knife. The second outstanding advantage of the dermatome is that a graft of very large size may be taken from locations not previously available. For instance, skin grafts have been obtained from the pectoral region and the scapular region in

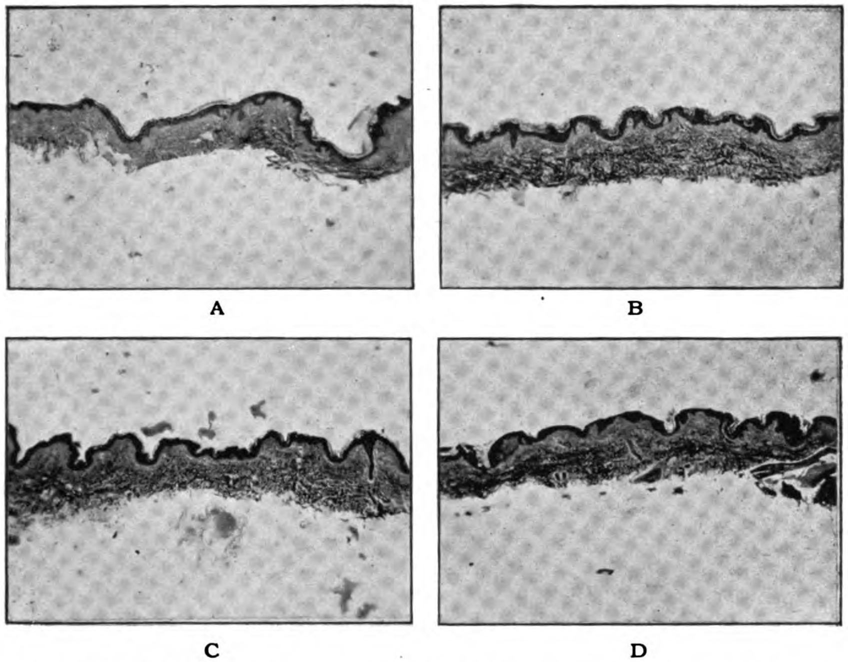


Fig. 29. Sections of Typical "Split" Skin Grafts. (A) Split skin graft from outer thigh of an adult male—thickness about .012 of an inch (.3 mm.) at maximum. (B) Split skin graft cut from outer thigh of boy age 9 years—thickness about .013 of an inch (.33 mm.) to .014 of an inch (.36 mm.). (C) Split skin graft cut from inner thigh of a fat woman—thickness about .013 of an inch (.33 mm.) to .014 of an inch (.36 mm.) at maximum. (D) Split skin graft from outer thigh of young adult male—thickness about .013 of an inch (.33 mm.) to .014 of an inch (.36 mm.) at maximum. (Padgett, *Surg., Gynec. & Obst.*, 1939, *69*:779.)

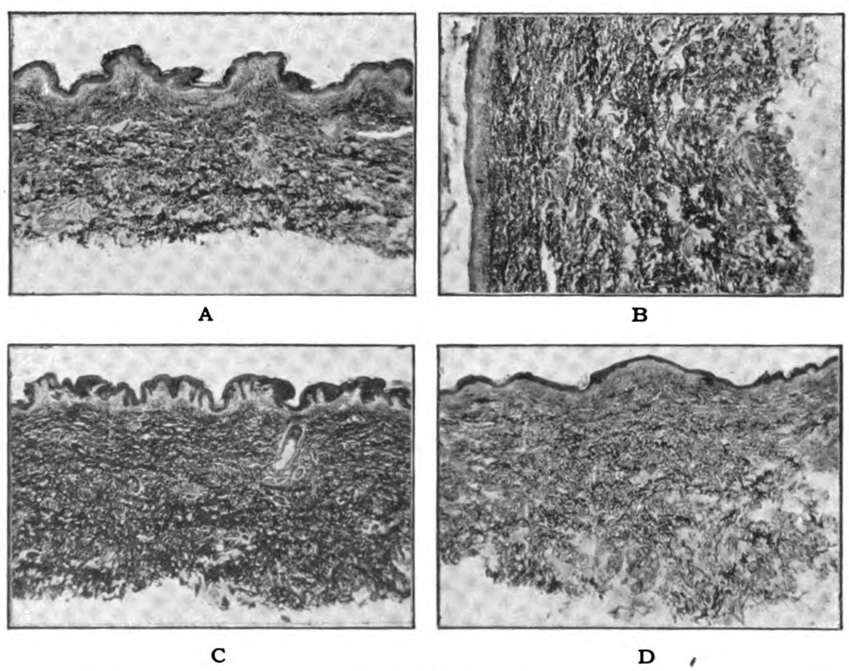


Fig 30. Sections of full-thickness skin grafts cut with scalpel showing variation in thickness. ×16. (A) Full-thickness skin graft cut with scalpel from the abdomen of an adult male; thickness about .032 of an inch (.81 mm.). (B) Full-thickness skin graft cut with scalpel from abdomen of an adult male about .040 of an inch (1.01 mm.) in thickness. (C) Full-thickness skin graft cut with a scalpel from the abdomen of male child age 8 years; about .034 of an inch (.86 mm.) in thickness. (D) Full thickness skin graft cut with scalpel from abdomen of an adult male from .028 of an inch (.71 mm.) to .034 of an inch (.86 mm.) in thickness. (Padgett, *Surg., Gynec. & Obst.*, 1939, *69*:779.)

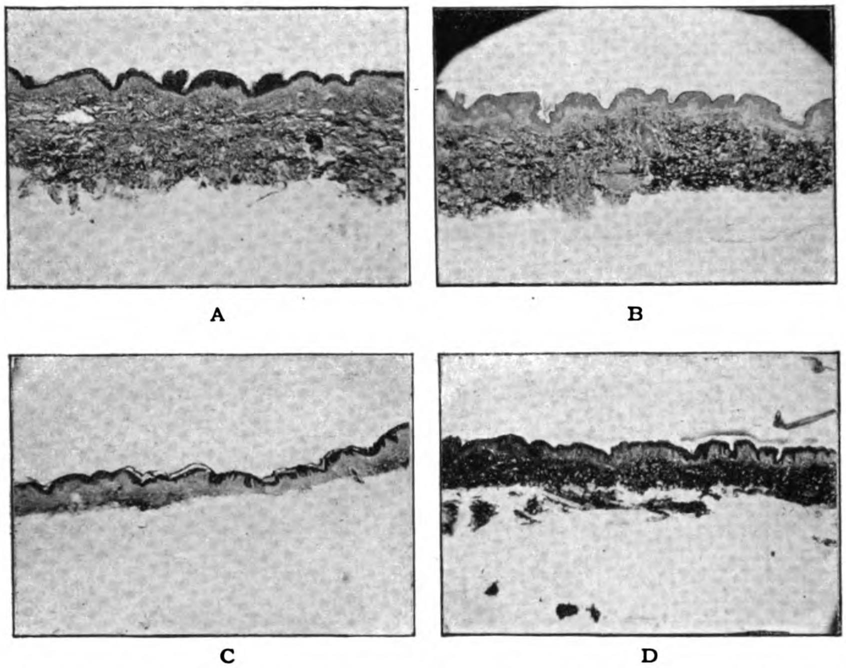


Fig. 31. Sections of thin and moderately thick calibrated skin grafts. ×16. (A) Male adult graft cut from abdomen about .010 of an inch (.25 mm.) in thickness used to cover a granulating area. A good "take." (B) Male adult graft cut from abdomen about .012 of an inch (.3 millimeter) in thickness used to cover a granulating area. A good "take." (C) Male adult graft cut from abdomen about .018 to .020 of an inch (.46 to .5 mm.) in thickness. Graft used to cover back of hand on clean raw surface. A perfect "take." No blistering. (D) Male adult graft cut from outer thigh used to cover clean raw surface of dorsum and palm of both hands. .014 to .016 of an inch (.36 to .41 mm.) in thickness. These last two are almost "three-quarter thickness" skin grafts. A good "take." (Padgett, *Surg., Gynec. & Obst.*, 1939, *69*:779.)

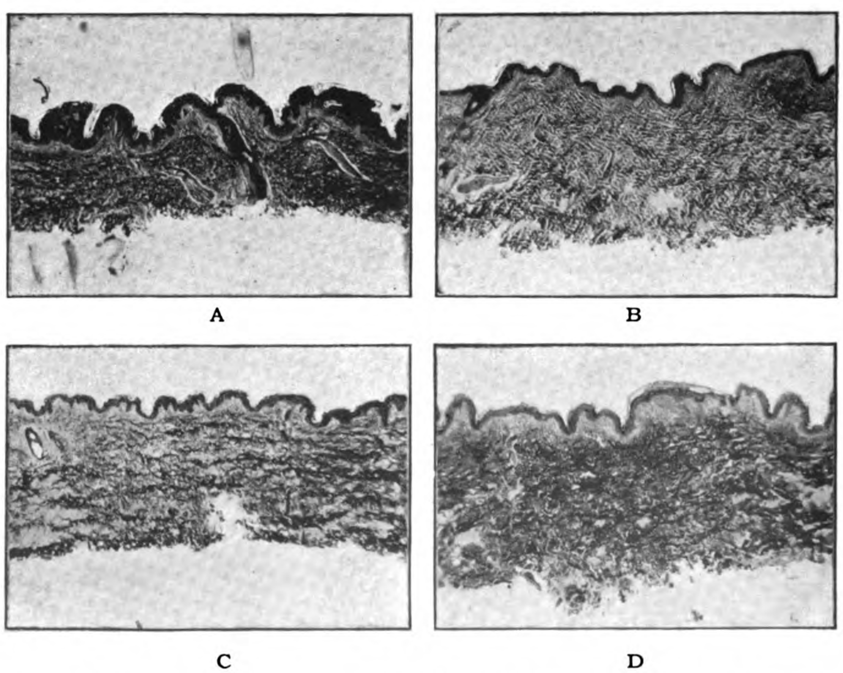
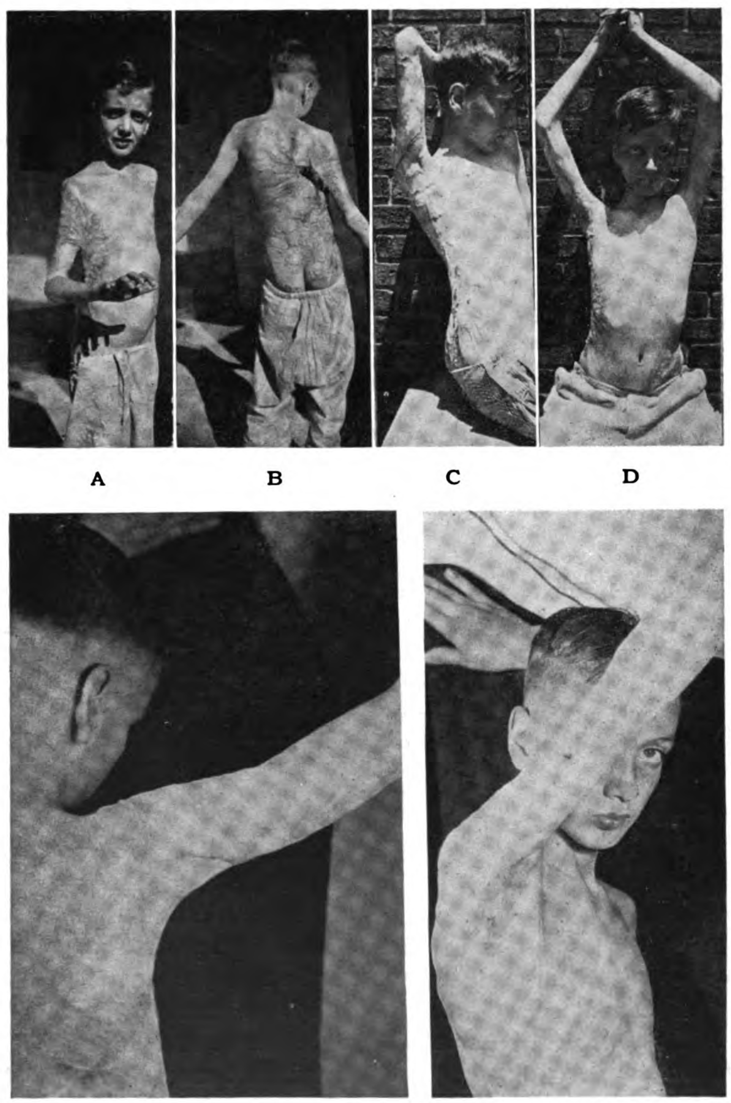


Fig. 32. Sections of new "Three Quarter Thickness" skin grafts. ×16. (A) Graft cut from abdomen of boy 8 years old, about .020 of an inch (.5 mm.) in thickness. (B) Graft cut from abdomen of woman, age 60 years, pregnant previously; about .025 of an inch (.63 mm.) in thickness. (C) Graft of male age 14 years cut from abdomen; about .025 of an inch (.63 mm.) in thickness. (D) Graft of male age 65 years cut from thigh about .030 of an inch (.76 mm.) in thickness. (Padgett, *Surg., Gynec. & Obst.*, 1939, *69*:779.)

markedly emaciated individuals; the lumbar region, the posterior gluteal region, relaxed pendulous abdomens, and even over the ribs, if the patient is not too emaciated. In all these regions the skin graft knife, despite the utmost dexterity of the operator, is of no great use.

Foremost, one can but be impressed by the area of skin that is available. This factor alone allows one to graft successfully a type of individual occasionally seen, who in the past has been nearly hopeless, as for example, the type of patient with a tremendously large denuded surface covering both thighs and legs on whom most of the remaining skin is on the trunk (Fig. 33-34).



A B C D

E F

Fig. 33. A boy who had a marked fixation of his arm to his chest wall due to an old heavy scar. **(A) Anterior view. (B) Posterior view.** The scar and granulations were excised. The arm was hyperextended leaving a very large denuded area from the elbow to the lower rib region. Calibrated skin grafts of deep intermediate thickness (three-quarter thickness) were taken from both thighs and applied to the raw areas. Four drums of skin were used. In this case the grafts were .018 of an inch in thickness. (C) and (D) Show the result about 3 weeks later. (E) and (F) Show the result one year after the grafts were applied. (Padgett, *Surg., Gynec. & Obst.*, 1939, *69*:779.)

A B

Fig. 34. (A) Example of a very severe cicatricial contracture of the neck and arm which was corrected by means of "Three Quarter Thickness" skin grafts of about .016 of an inch in thickness in three operations. This case was published in *Surgery, Gynecology and Obstetrics,* 1939, but since that time a small operation has been done beneath the chin to eliminate a defect in that region. The first photograph was taken October 18, 1936 when the child was 8 years of age. (B) Final result April 20, 1941 (age 13 years). Both the functional and cosmetic results are good. (Padgett, *Surg., Gynec. & Obst.,* 1939, *69*:779, and Padgett, *Ann. Surg.,* 1941, *133*:1039.)

In a case of this type with both legs denuded, we removed at the first operation 744 square centimeters of skin from the abdomen and anterior chest in six large sheets. This covered about one-half of the denuded area. Three weeks and a half later at a second operation, 781 square centimeters of skin were removed from a similar patient.* Because one can obtain a uniform large sheet of skin to drape over a form or stent, a graft cut by the dermatome is particularly satisfactory when a cavity is to be grafted.

If one has a large defect to cover on a baby one cannot cut by hand with a skin graft knife a graft of sufficient size to be useful. With the dermatome a graft of large size may be taken either from the abdomen or the chest. Again, in an individual who is very emaciated, such as a patient who has suffered from severe burns several months previous to the initial examination, it may be very difficult or impossible to cut sufficient skin from available areas with the large skin graft knife and do much in the way of resurfacing the involved area.

As a matter of fact, in our routine work practically all of our grafts are cut by the dermatome at the present time. The ease, the accuracy and the rapidity of the method recommend it.

Resplitting of Dermatome Graft

Zintel (1945) has an interesting article which shows that one can cut a fairly thick skin graft with the dermatome, leaving enough subepithelial elements in the donor area for regeneration and that afterwards one can re-split the skin graft while it still remains on the dermatome and double the amount of epithelium that may be applied to a granulating area. The deeper layer of this secondary split skin seems to take and form epithelium as well as the superficial layer. He has recommended this technique as one method of getting twice the amount of thin skin covering at one operation that one would ordinarily obtain.

* A warning might be wise here. A blood transfusion may be necessary because of loss of blood when too much of the body surface is denuded. The same factors are operative as when there is too much denudation following a burn.

A B

Fig. 35. (A) Keloidal scar of both sides of the cheeks due to a burn. This was corrected by excision of the entire scar and the application of a thick skin graft. (B) Appearance of patient three years later. The color and texture of the full thickness skin graft very nearly approach that of normal. (Padgett, *Arch. Surg.*, 1937, *35*:64.)

The New "Three Quarter Thickness" Skin Graft

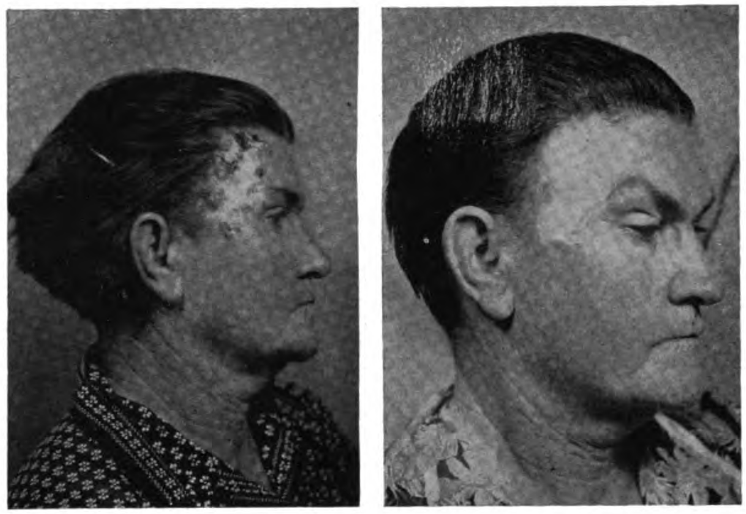
Our experience with the three quarter thickness skin graft, as cut with the dermatome, indicates that provided other factors, such as proper fixation, tension, hemostasis, pressure, and a clean field are obtained, the chance of failure to "take" is nearly eliminated if properly cut. Because of the certainty of "take" being increased, one can extend the magnitude of his reconstruction to limits not advisable previously. Difficult areas to graft with thick grafts, such as the lateral cheek, the neck and the axilla, and the dorsum of the hand become acceptable cases in which successful repair is to be expected and not just hoped for (Fig. 35-36-37). The fact that the graft shows little blistering of areas of necrosis causes the final appearance to approach that of normal skin (Fig. 35-36). Its appearance is as good as that of a full thickness graft after a perfect "take." These factors, plus the fact that the donor area does not have to be sutured, as it heals in from 10 to 14 days, (Fig. 38) has caused us to cease using the full thickness skin graft, except in babies where the amount of skin necessary is little as in the repair of web fingers.

To recapitulate, the new "Three Quarter Thickness" graft as cut with the dermatome is comparatively certain to "take." The new

A

B

Fig. 36. A patient who had a large marked scar on the leg and a cicatricial contracture of the popliteal space with a scar on the inner side of the malleolus which pulled the foot into a position of varus. After the scar was removed and the area split lengthwise of the leg to release the contracture, 3 large skin grafts .024 of an inch in thickness were removed from the abdomen and thigh and were placed from the region of the os calcis to about 3 inches above the knee in the posterior region. The scar on the malleolus also was excised to correct the varus. The idea here was to open up all contractures and to resurface the popliteal space. This was done in one operation. The photographs show the scar and the result 1 year after skin grafts were applied. The burn had occurred 2 years before we saw him. (Padgett, *Surg., Gynec. & Obst.*, 1939, *69*:779.)



A B

Fig. 37. (A) Basal cell epithelioma of the side of the forehead which had been unsuccessfully irradiated with a recurrence. This area was excised and "three-quarter thickness" skin graft .026 of an inch in thickness removed from the abdomen was applied. (B) Appearance 2 months later. (Padgett, *Surg., Gynec. & Obst.*, 1939, *69*:779.)

graft shows practically no blisters or local areas of necrosis. The ultimate contraction is reduced to a minimum. Good protection is offered. The donor area heals quickly (Fig. 39). The postoperative period of care is relatively short. Finally, as a rule, the usual run of lesions may be corrected in one operation.

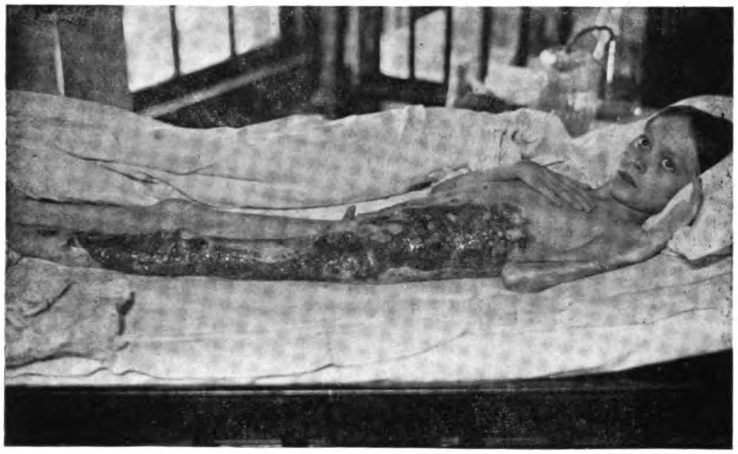
Summary

The properties of skin grafts in general, have been summarized. The development of the dermatome has removed many of the mechanical difficulties of cutting a skin graft of the necessary size and correct thickness. Microscopic examination of the thickness of the average graft as cut by various methods suggests a more accurate reclassification as to thickness. It is now possible to graft certain cases in which formerly a successful result was sometimes not obtainable. A graft cut at a level ordinarily not possible before the development of the dermatome has been described—a new deep "Three Quarter Thickness" skin graft. The relative merits of this graft as compared with the full thickness skin graft have been presented.

The Dermatome and Directions for Its Use

Essentially the dermatome consists of a half hollow drum, hand tooled to a perfect half circle with a centralized hand holder through which passes a centrally located shaft held by two bearings. To this centrally located shaft are attached bilateral arms which extend to and are attached to a knife holder. In the arms are bilateral calibrating mechanisms which allow one to change the distance of the knife from the drum at will. Before placing the knife the drum should be turned upward and locked by pushing the drum against the metal catch on the side of the stand. The knife should be placed in the holder with beveled edge downward and clamped with the metal clamp to the holder. By means of turning the screws in the side arms the knife blade is brought to or away from the drum at either end. The faintest contact of the knife with the drum may be taken as 0. The arm screw heads are calibrated in .002 of an inch readings. Thus, one may adjust the knife to or away from the drum by the side arm screws alone if so desired. However, after equal lateral adjustment there is a secondary method of bilateral adjustment. To the end of the shaft is attached a calibrated

flange. The ends of the shaft are set eccentrically in the arms. When the flange is rotated, the knife holder is raised up or down because this eccentric setting moves both sides concurrently. To separate the knife from the drum, the flange attached to the shaft is simply rotated in such a manner that the knife blade is thrown away from the drum to the desired



A

B C

Fig. 38. In this boy two operations were necessary. The granulating areas were first covered by thin calibrated skin grafts (0.12 of an inch in thickness) and he was allowed to go home. After several months he came back with a certain amount of contracture in the popiteal space. At this time we had a healed field with which to work. After crosscutting the scars, moderately thick calibrated skin grafts (.018 of an inch in thickness) were cut from the abdomen and applied over the denuded areas. (B) and (C) Show the functional result about three months after the second operation. (Padgett, *Surg., Gynec. & Obst.*, 1939, *69*:779.)

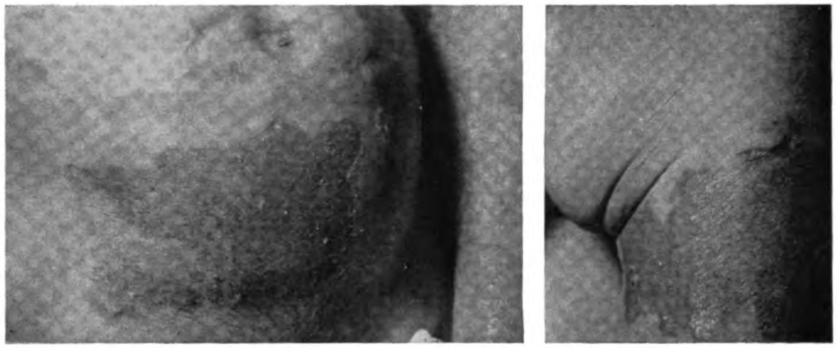


Fig. 39. Abdomen and thigh of the patient shown in Fig. 36. This photograph was taken 3 weeks after the skin grafts had been removed. The grafts were .024 of an inch in thickness. (Padgett, *Surg., Gynec. & Obst.*, 1939, *69*:779.)

calibrated thickness of the skin graft to be cut. The shaft, the holder and the knife can be worked crosswise of the drum at will by the hand. The sweep of the knife is about two inches.

First, the drum, and second, the donor skin to be removed is painted with a rubber cement by means of a brush just before the skin graft is to be cut. The drum is pressed against the skin and by rotating the drum slightly the skin is drawn up somewhat. The knife is then passed backward and forward, cutting the skin at the predetermined distance from the drum. The skin graft is fixed to the drum as it is cut. Later with a slight pull one may remove the skin from the drum.

There are several precautions to be taken about the cement. It should have some body but it should run easily. If the cement is too thick, its adhesive qualities are diminished. Shake the cement well before using and do not let it stand out in the open, as the ether in the cement evaporates rapidly. The temperature influences the thickness of the cement somewhat. In warm weather it is thinner than in colder weather. If the cement is too thick, add some ether and stir. If it is too thin, allow some of the ether to evaporate. One should not put the cement on the drum when the drum is warm. This will cause the cement to boil and will nullify its adhesive qualities. Water or blood also will nullify the adhesive qualities of the cement. Therefore, no moisture should come in contact with the cement or with the area from which the graft is to be cut. The part of the body from which the skin graft is to be cut should be perfectly dry. The antiseptic previously applied should be wiped off with ether before the cement is applied to the skin. The donor area to which the cement has been applied should be allowed to dry until the cement ceases to glisten. The brush should be rinsed in ether and dried on gauze before each use. The coating should be fairly thick but even on both the drum and the donor area.

If the surgeon is right handed, the drum is taken in the left hand and the handle of the knife holder in the right hand. After the cement on the donor area has ceased to glisten, indicating that it is now half dry, the drum is placed on the area and held there for a few seconds to allow time for it to adhere to the drum. The knife is worked from side to side, making quick rather short strokes of the knife holder. The best way to handle the drum is to roll it, lifting the skin slightly. The surgeon cuts toward his body and leans forward over the drum to observe how the graft is being cut as he rotates the drum away from his body.

The knife blades should be kept sharp. This facilitates very much the cutting of the skin graft. The edge should be slightly rough, like a Bard-Parker blade—not like a straight edge razor, which has a more or less smooth edge. The blades can be sterilized in Bard-Parker Solution.

The skin graft machine itself may be boiled or dry sterilized, but the drum should be

thoroughly cooled and dried before the cement is applied. A little three-in-one oil applied to the shaft and adjusting screws will facilitate considerably the working of the mechanism.

A knife holder is supplied with the dermatome which can be used for the purpose of honing the knife blade on an oil stone or for cutting a "Thiersch" or "Split" skin graft by hand. As a rule, however, after using the blade four or five times or if it is handled carelessly, the knife blade should be returned to the sharpener for re-sharpening.

The Forming of and the Relining of Cavities With Skin Grafts

Many defects, which involve body cavities, as, for instance, the mouth, nose, and orbit, can be relieved or reconstructed by a replacement of lost mucosal or epithelial lining, or a new cavity can be constructed (vagina) by means of skin grafting on a mold (Chapter XXVI, Fig. 399). Up until recent times, the problem of resurfacing cavities was an unsolved one. The matter approached solution when Esser demonstrated that free skin grafts could be successfully grafted as a lining membrane in the mouth, and that in such a case it functioned under conditions originally quite foreign to it. Esser in 1917, through an incision made beneath the chin without opening into the mouth cavity, introduced a mass of modelling composition covered with a Thiersch graft. The incision through which the stent and skin graft had been inserted was closed. Later this skin lined cavity was opened from above. The destroyed buccal sulcus was reproduced quite satisfactorily. Esser termed his method "epithelial inlay grafting."

Gillies first adapted the Esser inlay to surface use in the method known as the "Epithelial Outlay." He first used it to correct ectropion of the eyelid. A description of the operation follows:

"An incision is made, skirting the lid edge, and the lid liberated by dissecting freely till closure can be effected without tension. In the resulting cavity is buried a closely fitting stent mold covered with a Thiersch graft, over which the edges of the incision are sewn with horsehair, the sutures taking up the edges of the skin-graft. After some eight days the stent either falls out or is removed, and the lid falls easily into position." Gillies, also, first lined a syphilitic nose by the inlay method.

Gillies, Waldron and Pickerill, in 1918 used the principle of the "outlay graft" by introducing a stent covered with a skin graft directly into the mouth where it was found to "take" on a freshly denuded surface in the presence of salivary secretions which contained the bacterial flora of the mouth. The method now has a rather wide application in reconstructive surgery.

Technique: In constructing a new subcutaneous lined cavity or in repairing an obliterated one, it is necessary to observe certain rules if the end result is to be satisfactory. Allowance must be made for a considerable amount of subsequent contracture. In other words, one must overcorrect the defect. The amount of contracture will depend somewhat upon two factors—the thickness of the graft and the pliability and elasticity of the underlying bed. The cavity must be overdistended by the mold and the stent must fit the cavity accurately. The skin graft should be in one piece.

For the routine case, when overcorrection is easily obtained so that contracture is allowed for, as when one is deepening the moderate obliteration of gingivolabial sulcus (Chapter XXII, Fig. 293) or correcting an ectropion of an eyelid or lip (Chapter XIX, Fig. 214), an accurate and easily removable mold of dental compound is made of the cavity. A one piece skin graft of the calibrated intermediate type is cut from an appropriate part of the body such as the inner arm, inner thigh, or posterior to the ear. This graft is then draped, raw surface outward, over the mold. Mold and graft are then inserted into the cavity or gutter. When the operation has been on the gingivolabial sulcus, if any circumferential sutures are needed to hold it in position, they are placed about the mold and tried over an external gauze roll or rolls of dental cotton to prevent cutting of the skin.

The after care is simple and is directed towards keeping the mouth clean with washes. Usually high caloric fluid diet at first is advisable. After a week the preliminary mold is removed. The cavity is rinsed, and the mold which will be used for the next month or so is placed in position.

When the operation is performed to correct an ectropion of the eyelid or lip, a rolled stent is formed (Chapter XIX, Fig. 212) of the proper size. The skin graft is draped over the stent. The stent and the graft are then laid in the denuded gutter, which is present after the scar has been crosscut and removed. Interrupted sutures are now taken both through the skin edges and graft on either side of the stent. No dressing or only a dry dressing is all that is necessary. The stent is removed in about six or seven days.

Thus, if the situation is one where considerable overcorrection can be made, it is not necessary, ordinarily, to keep the mold in place after the seventh day.

In the relining of luetic noses or building of a new urethra (Chap. XVIII, Fig. 179) with a skin graft, we have had practically no experience as we have preferred to use skin flaps for these procedures. However, in the case of relining the nose for some such lesion as congenital syphilis, McIndoe emphasizes that the mold should be kept in place three or four months, and he cautions against ever removing the stent for more than a few hours, until the contractile phase is over. In case there is an inflammatory reaction he says: "Certainly the worst thing to do is to remove the stent entirely and allow the inflammation to subside. Drain an abscess after localization but keep the stent in place if possible." He advises leaving the mold in place from five to six weeks in the cases of contracted orbit. In the formation of a new urethra the catheter is left in place three or four months.

The mold may be buried for a considerable period of time provided it is made of some material which does not absorb secretions. A small drain hole should be left for the escape of secretions during the healing phase. When one wishes to line a flap for the purpose of rebuilding some organ such as a part of the nose it may be advisable to allow the stent to remain *in situ* until the contractile phase of the graft is over. When one is particularly desirous of preventing all the contracture possible, particularly if the field is an aseptic one, it is often advantageous to use a rather thick, deep, calibrated, intermediate skin graft. The thicker the skin graft the less the tendency to contracture.

When the cavity to be grafted is likely to be quite marked, one should work in cooperation with some one skilled in making splints and prosthetic appliances. Sometimes much ingenuity and patience are required. It may be advisable to design and attach a part of the retention mechanism before the operation. As, for example, when the buccal sulcus is obliterated widely and there are sufficient teeth present, a metal cap splint with a detachable "snap on" device to hold a form may be constructed and placed on the teeth before operation. In edentulous patients, a combined upper and lower spring retention apparatus sometimes may be advisable. Two impressions are taken and two molds are made of the cavity. One is given to the dental technician and one is used to hold the graft in place for the first week or ten days. The dental technician then has a week or so to build the appliance which may be inserted into the newly formed cavity when the original form is removed.

For relining a nose, Gillies recommends that the mold be made in two pieces—one for the nasal cavity proper extending up over the nasal bones, and a second lying against the first, which occupies the lower half of the cavity and the entrance from the mouth to the nose. The double block facilitates removal and reintroduction. A good stent for the building of an artificial vagina is a condom filled with paraffin. (Chapter XXVI, Fig. 399). Later a smaller stent can be made of some non-irritating material. For a time, at least, this should be worn continuously and then after four or five months at nights only.

Wheeler, who was most successful in relining an eyesocket, placed stress on the following

points: (1) complete thinning of the eyelids of most of the tarsal cartilage; (2) deepening of the infra-orbital sulcus to the bone; (3) deepening of the external sulcus to the bone; (4) complete freeing of the tissues attached to the levator palpebral muscle without injuring it; (5) deepening of the sulcus about and freeing of the caruncle; (6) the use of a flattened lozenge shaped stent as large as could be inserted. Sometimes the outer canthus was widened to allow insertion of the stent. (7) The covering of the stent with a very thin Thiersch non hair-bearing graft. He gained by this means a flattened cavity. The tissues of the orbital cavity were not removed. They were used to push the new prosthesis well forward. Thus, he gained practically no deepening of the sulcus just below the upper eyebrow. He left his stent in for only a period of two weeks or so. If the graft was thin enough in some cases some of the tear ducts remained patent. Wendell Hughes, New York, has used about one-third cut of a hollow rubber ball for the eye-socket with great success. This has the advantage that one can squeeze up the one-third part of the rubber ball somewhat and can insert it through the eyelids into the larger cavity back behind.

General Considerations Pertinent to Successful Skin Grafting

Before attempting to transplant a skin graft, cognizance must be taken of the general condition of the patient, the donor area which is to be used, the type and condition of the area on which a skin graft is to be placed, the nature of the tissue lost and the optimum time for skin grafting.

General Condition of the Patient

Skin grafts stand a better chance to "take" if the patient is in good condition. Grafts "take" better in children than in the aged but the difference is not very marked. Individuals debilitated with chronic disease show a greater tendency to infection. An anemic individual is a poor subject for a skin graft.

Generally, the question of whether or not the patient will withstand an operation, which seems imperative, arises after some such injury as a severe burn which denudes a large area. Often, such a patient reaches a point before he is seen by the plastic surgeon which makes the decision whether or not to attempt a skin grafting operation very difficult. It may appear that the patient is losing ground, becoming generally more debilitated and, on the whole, the patient's condition is such that the transference of sufficient skin to cover the denuded area may risk an immediate operative fatality. The decision as to the time to wait or attempt operation must be made by balancing all factors of the patient's condition in conjunction with the chances of supporting the patient with blood transfusions and other supportive measures both before and after operation. For the effects of dehydration, hypoproteinema, vitamin deficiency and acid diet on wound healing after a severe injury such as a burn, see Chapter VIII—The General Care of Wounds of the Soft Tissues.

The Donor Area

Often some attention should be given to the selection of the donor area. In the past, this presented quite a problem because, with the methods then in use when the thighs and legs were both unavailable as donor sites as in the case of a nearly complete burn of both extremities, it is sometimes not technically possible to remove sufficient skin from the trunk. Now, with the dermatome, this difficulty is eliminated. For most routine lesions of the extremities of the body, skin taken from the abdomen, thighs, or buttocks is used.

When some area, such as the face, is to be grafted the best result will be obtained if a donor area is selected which is covered with skin that is nearly the same thickness, texture, and color as that which normally is found in the recipient site. The skin back of the ear and the skin of the upper eyelid is often selected for the repair, for example, of the lower eyelid. The skin of the inner side of the arm is quite thin and fine in texture but has a tendency to be rather white for the face.

When hair is desirable, some site such as the pubic region or the scalp may be selected

depending upon the structure to be imitated. A full thickness scalp graft for example should be used to reconstruct an eyebrow. On the contrary, if hair is not a desirable feature, especially if a thick graft is being transferred, one should select a non-hairy donor area. Individuals, of course, vary somewhat as to the color, texture, thickness, and hairiness of their skin and they may even vary individually regionally as to these factors.

Condition and Type of Area on Which the Graft is to be Placed

The type and condition of the base on which a skin graft is to be placed are the most important factors. When the other factors for success such as proper pressure and fixation are met each type of skin graft has its optimum assurance of "taking" on an aseptic base such as a fresh accidental wound or a freshly denuded surface following a clean operation. Under such conditions the ideal type of skin graft is a thick skin graft. The type of skin graft will more nearly duplicate the surface, and the tendency to contracture is less. Because of the risk of a failure to "take," a thick skin graft ordinarily is not selected to cover a granulating surface even if the surface is as free from contamination as it is possible to get it by antiseptic wet dressings. A thin graft or one of superficial intermediate thickness should be selected to cover a clean granulating area.

When the granulating area is unclean all skin grafting operations ordinarily should be deferred until the surface has been cleaned up. The argument that such and such a graft is advantageous on an unclean surface should not be a factor. The point is to get the surface clean as any graft will then stand a better chance of "taking." The only exception to this is certain granulating areas that cannot be rendered surgically clean because of continual contamination. An example of this is the presence of a fecal fistula in the neighborhood of a granulating ulcer. For such conditions, the implantation graft is the only graft indicated.

The type of base that is to be grafted has an influence on the type of graft selected. Absolute contact between graft and base and no movement between graft and recipient site are essential for a good "take" in skin grafting. Therefore, a smooth convex base where the underlying structures are immobile is the ideal base. The forehead is an ideal place to get a good "take" while on the neck especially over the thyroid cartilage, to get a graft to "take" may be almost impossible because of the swallowing movement of the laryngeal box. The amount of blood supply in the base is important. For example, after excision of an old scarred varicose ulcer of the leg the recipient site may have such a poor blood supply that a considerable degree of uncertainty may be present as to the ability of the graft to develop a blood supply. In one case of leg ulceration, although the man was only middle-aged, the vessels were so arteriosclerotic that a "take" was not obtained. On a cancellous bone, as exists after the removal of the outer table of the skull, only about fifty per cent of a skin graft will "take," and as much of a thick graft will "take" as a thin graft.

Nature of the Tissue

The nature of the tissue lost brings up the question of skin flap versus skin graft. Provided that a skin graft is indicated, the relative importance of two factors must be weighed: (a) the cosmetic result and (b) the functional need. When the appearance is of prime importance, the donor area must be carefully selected as to color, texture, and the presence of hair, and as thick a graft should be used as will allow assurance of a good "take." Obviously, when function or mobility is the first consideration, the choice of the donor area selected is not so important. Of more importance is the quantity of skin used and its thickness. Sufficient quantity must be applied to allow for the amount of contracture likely to occur in a particular region and, also, allowance must be made for the amount of contracture characteristic of the particular thickness of the graft used. For healed contractures of the extremities and body, deep intermediate grafts are preferable. But to reline a cavity.

such as an eye socket, a thin graft is preferable. When the graft will have to withstand trauma, as in the palm of the hand, it should be as thick as is consistent with an assurance of a good "take."

Optimum Time for Skin Grafting

When considering the optimum time for skin grafting, one has to take into consideration the cause of the loss. The immediate resurfacing of fresh operative defects or clean accidental destruction is most satisfactory. However, after completely excising a lesion, when one has considerable scarring of the base, it may be wiser to place a sterile dressing on the area for a few days. There are two reasons for this: First, because of the scar it may be almost impossible to get proper hemostasis; and second, if the blood supply of the base is deficient, some formation of granulations, provided they are kept clean, may enhance the certainty of the "take." An example of such a situation may follow the complete excision of an old large leg ulcer.

In the case of accidental wounds, the nature of the wound, the time it is seen, and the extent of the bacterial invasion will all influence the optimum time. If the wound is seen early, although it is somewhat contaminated, if it is carefully cleaned, irrigated, and debrided as needed, often the time for placing the skin graft is at once. On the other hand, if the wound is infected, covering a denuded area with a skin graft will be a useless gesture. The optimum time to graft contaminated wounds and wounds with considerable surface destruction, such as an acute burn, is after the infection is completely controlled, all dead tissue has separated and a good clean granulating base has been obtained. In the ordinary mildly contaminated wound, this state of affairs is usually present within two or three weeks, but following a burn, a clean granulating base cannot be obtained usually before the third or fourth week.

Following a burn, Young (1944) has advocated immediate skin grafting after cleansing and moderate judicious debridement. The disadvantage of this would seem to be lack of ability to determine the depth of destruction at an early date. Often the patient's condition does not tolerate immediate skin grafting with the necessary operative procedure and additional skin loss. Lamont, Converse, and McIndoe recommend the use of skin grafts not only in cases with superficial loss but in injuries involving tendons, bones and joints, where they believe immediate coverage is important. Such need should be promptly recognized and early coverage practiced. Particularly is this true in areas of functional importance. In war wounds, the skin serves as a "skin dressing." This procedure avoids complications and greatly reduces the healing period of the wound.

—7

This method was found applicable to both early and late closure. Lamont stresses that the skin grafts will grow well on any fresh wound, periosteum, perichrondium, muscle, fascia, tendon, or in the mouth. However, it will not control the underlying fibrosis.

The time of application of the skin graft is determined by the appearance of the wound. After wet dressings, as soon as it assumed the appearance of a surgically cleaned wound, the grafting operation was performed.

Preoperative and Postoperative Care When Grafting with Thin or Superficial Intermediate Skin Grafts

In every day practice one encounters two types of patients in whom grafting with thin or superficial intermediate skin grafts is indicated: (a) a granulating surface and (b) certain aseptic denuded surfaces.

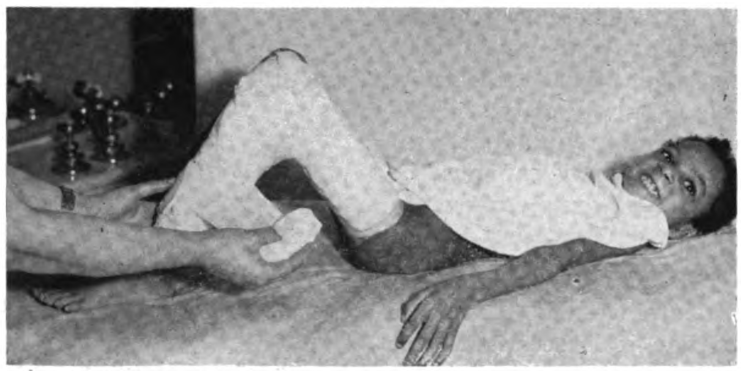
On a Granulating Surface

When grafts are placed on a granulating surface, success depends to a large extent on the condition of the wound. It is most important that the granulations be clean, firm, red in color and not very exuberant. It is not necessary to have the bacterial count absolutely negative. When the wound is clean, the bacterial count of the secretion on the wound will not be high. The infecting organism is of importance in the determination of the readi-

ness of the area to accept a graft. Greeley is of the opinion that the bacillus pyocyaneous is most to be feared. McIndoe states that in his experience the organisms of which to be most wary are hemolytic Staphlococcic Aureus and sulpha resistant hemolytic Streptococci. Our work in culture of wounds largely substantiates these findings. Smith does not graft until he has a culture negative for Streptococci. Probably the best criterion for the chances of a good "take" is the appearance of the wound. When the edges show evidence of epithelization the chances of a "take" are good.

Preparation of the Bed

It has been our experience that the best method to prepare a granulating area for grafting is to apply continuous wet gauze dressings which are changed at least twice daily. We generally use a heavy roller gauge, which is wrapped around the granulating area, with sufficient cotton on the outside to hold the moisture throughout the day (Fig. 40). At intervals of about once every hour some antiseptic solution such as Dakin's, azochloramine or even hexylmethylamine, magnesium or saturated boric acid solution is poured upon the



A

B

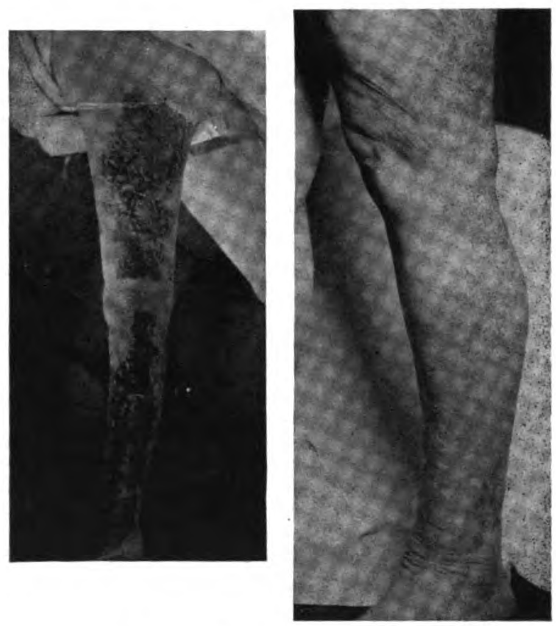
Fig. 40. (A) The method of applying a wet roller gauze roll to a wound when the time has arrived for separation of the dead tissues from the live soft tissues. Sufficient cotton pads are placed between the gauze to hold the moisture well. Externally a layer of rubber surrounds the gauze to prevent too rapid evaporation. Periodically the gauze is remoistened. The roll is changed morning and evening. (B) If much pain is complained of when the roll is removed, if the condition of the patient permits he may be placed in a tub immersion for a few minutes and the gauze removed under water either by the patient himself or by the interne. The simplest solution to use is hypertonic saline solution. Any antiseptic solution, if nontoxic, will act the same. (Padgett, *Arch. Surg.*, 1937, *35*:64.)

cotton and gauze dressing. When the wound is particularly sluggish, as for instance an old varicose ulcer, heat is applied as an additional stimulus, and if stasis is present the part is put in a position to eliminate this if possible. The cotton is not allowed to come in contact with the granulating area. The gauze should be rather fine so that no lint will be collected on the granulation surface.

If the wound is such that change of dressing is particularly painful, if the morale of the patient is low as in children badly burned, if the wound is particularly dirty or if there is a good deal of slough attached, the patient is very often placed in a tub bath and submerged in a solution of hypertonic saline. After removal from the tub the patient is either placed on a clean sheet beneath an electric light canopy and no gauze or only loose wet gauze laid on the wound, or a roller gauze is applied according to the type of wound or the morale of the patient. Such a method of treatment removes all crusts and scabs, and all the slough, as soon as the line of demarcation is well formed. The preparation of the granulating surface is the most important factor in obtaining success with this type of skin grafting.

There are many other solutions just as valuable as the ones we have mentioned but it just happens that we have not used them to any great extent. Boric acid solution sometimes is toxic when placed on too large a granulating area. Dakin's solution, when properly prepared may be difficult to obtain. Acetic acid (2 per cent) is useful when pyocyaneus infection is present. Some of the other solutions are rather expensive. We believe that the most important factor is the establishment of perfect drainage by a continuous moist pack. Bi-daily changing of the dressings is also helpful. It removes bacteria, it aids in removing any loose tissue or slough which is about the wound and may be harboring bacteria, and it stimulates the growth of granulation tissue. These factors, we believe, along with the condition of the host, are the important ones. The use of this and that preparation, without attention to these basic fundamentals, ordinarily tends to discourage success.

Appearance of Bed Before Skin Grafting. When grafting skin on a granulating surface, the appearance of the granulating surface should be used as the index to the time of grafting. The proper appearance is present when the surface is free from evidence of greyish slough or any gross pus, and the granulating base is firm, not too exuberant or watery, and the color of the granulations are a "cherry red" (Fig. 41). If the granulations are exuberant, a rather firm, tight, meshless bandage will aid in getting a firmer base by squeezing out some of the watery fluid. Anemic individuals do not present granulation surfaces of



A B

Fig. 41. (A) A large granulating wound of the leg of a patient ten days after beginning treatment by wet dressings and occasional tub immersion. She was burned thirty days before and was cared for at home by another physician, who used an ointment dressing. With the patient under gas anesthesia a large thin graft was applied from the opposite leg. Ninety per cent of the graft took. Thin grafts were taken from the inside of the left thigh, the outside of the right thigh and from the back. When taken along with the granulating area, owing to the burn such rather high percentage of body area was superficially denuded that about twelve hours after grafting skin from the inside of the right thigh, abdomen and back the patient showed signs of a mild "shock," which was interpreted as due to too wide an area of denudation (granulating area plus weeping area from which skin had been removed). A blood transfusion corrected this. (B) The legs one year later. Extension and flexion were normal. (Padgett, *Am. J. Surg.*, 1939, *XLIII*:627.)

the proper texture and color. When evidence of an anemia is present, a blood transfusion should be given. Bacterial counts on smears are of some value. When we have attempted skin grafting without these criteria being fulfilled, a part at least, and usually most of the graft failed to "take."

Cleanliness. Besides the points already alluded to, we wish particularly to stress that the cleanliness of the method and repetition of the dressing twice daily is regarded of utmost importance in shortening the period of time necessary to give a proper granulating bed. Besides the general condition of the patient, the most important aid to early epidermatization from the circumference of the wound is cleanliness. Reid, in an article on wound healing has questioned this concept. He states that the edges of the wound, where epithelium is regenerating, should not be traumatized by a type of dressing which sticks, or by repeating the dressing too often. On the other hand, he admits that in application, cleanliness is seldom too great. Often, the factor that one wishes especially to promote is not so much wound healing but preparation of a base so that infection cannot destroy the graft before it "takes."

The usual cause of loss of transplant is the development of infection beneath a part or all of the graft. This usually is due to desultory preparation of the granulating surface along with an error in judgment as to the time when the surface is in condition to receive a graft. In a few instances, improper fixation will be the basic fault.

Application of the Graft. After cutting, the graft is laid over as much of the denuded surface as its size allows. With one running stitch of silk suture it is then basted or whipped to the normal skin. An effort is made to maintain a degree of tension on the graft equal to that of normal skin. If we have any idea there is some chance of the graft slipping on its base, we very often quilt the graft in with stitches. We also do this when the graft is applied over a rather sharp concave area. In other words, the graft is stitched to the bottom of the concavity.

Before a dressing is applied, any blood clot underlying the graft is expressed from beneath it by pressure on a roll of gauze.

Machtfeld Sano presented a method of skin grafting based on the principles of tissue culture. Observing that in tissue culture the most satisfactory cell growth is obtained by the use of homologous plasma and tissue extract and that in such cultures fibroplastic proliferations normally begin within a matter of a few hours, she felt that tissue grafting could be accelerated by the use of a coagulum between the recipient area and the skin graft. The coagulum consisted of two solutions, a solution of heparinized plasma, and the other of buffy coat and Tyrodes. The latter was referred to as a cell extract. The cell extract was applied to the graft and the heparinized plasma to the recipient area with a camels hair brush.

Similar in principle is the fibrin fixation of skin transplants. The method also aims to reduce the number of sutures, to avoid the use of compressive dressings, and to extend the application of skin grafts to areas which formerly were prohibitive because of the difficulty of maintaining compression. These workers apply tropical thrombin (75 mg. diluted to 10 cc. with saline) to the recipient area and. after immersing the skin plasma, apply the graft to the recipient area and maintain pressure until adhesion is attained.

Sano thought that the graft took more quickly after the application of plasma and cell extract. This has not been the experience of other surgeons. As a matter of fact, the body itself furnishes the cell extract and plasma fairly quickly. Brown before the American Orthopedic Association, in discussion of Sano's paper, showed a case in which he had placed 6 small grafts on the same area and used various methods of application including Sano's. Each graft took at the same rate of time. To us it would seem that this method possibly has an application in areas like the abdomen and over the chest where it is hard to maintain absolute fixation because of the movement of the abdomen or chest under the dressing. In other words, if the procedure has a practical use it would be primarily one

of area fixation. Greeley, in his report of Current Experience of the Army and Naval Personnel, writes as follows in regard to the application of the method: "We have tried various original and modified applications of the coagulum contact technic but in our hands we have not had any greater success than with the well standardized procedures. Furthermore, we have lost surface area in attempting to follow the Sano plan because of the contraction of the graft by virtue of its own elasticity. Moreover, we have noted repeatedly that when split thickness grafts are applied, a natural coagulum develops rapidly between the raw surface of the graft and the underlying bed."

Removal of Ulcerated Area Followed by Grafting of the Base. Sometimes a very successful method of applying grafts, particularly on old ulcerated areas, is to totally excise the granulating area and all surrounding scar and get down to a hard firm fibrous tissue base which is relatively sterile. The graft is grown on a base which has the advantage of having less scar in it, but has sufficient blood supply to allow the graft to "take" readily.

It must be remembered that layers of old, firm hard scar beneath the graft will decrease its ultimate vitality and cause it to be more vulnerable to any injury that it may sustain. Heavy, deeply scarred areas have a lessened central blood supply and tend to stasis. *Such tissue is very susceptible to trauma. After trauma, if infection occurs, the destruction is likely to be considerable.*

When the granulating base is relatively new, large thin grafts show a greater tendency to "take" well if the granulation tissue is not interfered with, but, as we have just mentioned, in many cases sufficient fibrosis has occurred to give a firm scar base. The chances of a "take" after slicing off the granulations and all or a part of the yellow scar base, will be found to be good. Often some of the contracture is relieved and a better functional and cosmetic result is obtained.

In some patients not seen until several months after the original injury, healed contractures will have formed, but a part of the surface may have remained unhealed. In such patients it may often be possible to remove the granulating area by wide excision through healed tissue after which the contracture may be crosscut so that the contractural deformity can be corrected. The application of a rather thick calibrated, deep intermediate skin graft, along with placing the involved member in an overcorrected position, often will correct the condition in one operation.

Postoperative Care. It has been stated that more has been written on the dressings and postoperative care of skin grafts than on any other phase of the subject. In most of these contributions, many of which are a bit lengthy, the factors that will be found most valuable in the promotion of a quick, sure "take" are either not mentioned or are not recommended. These factors are: (1) absence of virulent infection; (2) proper fixation; (3) proper pressure; and (4) adequate provision for drainage. Although some fixation and pressure can be obtained with almost any good, ordinary, well applied dressing, the best methods according to our experience are not sufficiently stressed.

Good continuous drainage is necessary after the application of a skin graft to a granulating surface. The wound can be rendered only partly clean. Any secretion drying at the edges of the graft may block drainage. An ointment dressing impedes drainage. The dressing most likely to encourage proper drainage is a continuously wet dressing.

Our usual routine has been as follows: After laying the graft upon the granulating surface, the same type of a thick roller gauze dressing is applied, as previously described in the preparation of a clean granulating surface for skin grafting. Customarily, on convex surfaces and always on concave surfaces, a large, soft, wet marine sponge is laid over the grafted area outside of the gauze. Sometimes a few Dakin's tubes are laid in the dressing. This sponge is bandaged down snugly to maintain a proper pressure. This dressing is not to be changed for four days. During this period in order that the graft will not be pulled away from its base, the dressings are kept saturated with one of the solutions previously mentioned in our discus-

sion of the preparation of the base for grafting. When the graft is located in such a way that joint or muscular movement might cause it to slip, a splint of some type should be used so that fixation is definite. When snugly applied, sufficient pressure is given to hold the graft in contact with its base. On the fourth day, the dressing is changed and reapplied. On each successive day, until the graft is healed, some emollient ointment may be applied for a week or so.

On Aseptic Denuded Surfaces

The factor of drainage is not so important when the denuded surface is an aseptic one; but the factor of pressure and fixation is equally as important as when grafting upon a granulating surface, and the factor of tension assumes possibly a greater importance. The method of application of a thin graft on an aseptic denuded surface is the same as on a granulating surface. The prognosis for a "take," when the graft has been properly applied, is considerably better—about 100 per cent, and this estimate includes grafting not only on raw surfaces but in relatively unclean fields such as the mouth.

In the type of case which has healed but has a heavy scar that must be excised, often there is considerable oozing following excision. In some cases when this cannot be controlled by sutures, by applying immediate pressure, clot formation beneath the graft may be prevented. In such cases, it may be better judgment, therefore, to apply a sterile dressing immediately after excision of the scar, and to wait until the following day or the second day after excision to apply the skin graft. Hemorrhage at this time has ceased, and sufficient time has not elapsed for the surface to become clinically infected.

Technic. The technic outlined in the following pages with special reference to the thick skin grafts is, also, particularly applicable in growing a thin skin graft on a fresh denuded surface.

For the reason just mentioned, namely, that early drainage is not readily a factor when applying a thin graft to an aseptic denuded surface, as it is after grafting a granulating surface, the postoperative care may be considerably different. (See the comment on postoperative dressing for thick skin graft on an aseptic denuded field under next heading.) The same principles are involved and the same method is applicable to a thin skin graft on an aseptic denuded surface.

GRAFTING WITH THE "THREE QUARTER THICKNESS" OR FULL THICKNESS SKIN GRAFTS

A full thickness skin graft is still the graft of choice for lesions in which the area to be grafted is small, and the situation is such that the likelihood of a failure to "take" is negligible. In children this is especially true. In the correction of "web" fingers or when a skin graft from behind the ear, from the scalp or an eyelid is used. The "three quarter thickness" graft, in particular, is applicable for coverage of the following types of surfaces: (1) an aseptic denuded surface caused by the operative removal of some lesion or some tissue; (2) the reconstruction of a cavity, if the field is aseptic; (3) for coverage of the resultant denuded area after release of a cicatricial contracture.

Operative Factors Conducive to Success

To obtain the maximum success with the three quarter thickness or full thickness skin grafts, the following factors are significant: (1) A sterile field increases the chances of success; (2) a dry field with little or no oozing of blood is important. Consequently, all the vessels should be tied with the finest suture material. When there is any question of lack of hemostasis, a hole should be made in the skin to prevent the accumulation of blood serum beneath the graft. (3) The skin should be cut through the fibrous tissue layer of the corium in such a manner so that all fat is separated from the graft in cutting a full thickness graft. (4) The graft should be sutured in place under moderate tension to open the endothelial spaces; (5) the graft should have absolute fixation; (6) sufficient pressure should be applied to maintain definite contact with the underlying raw surface. As suggested by Blair a fairly adequate pressure dressing

on a concave uneven structure is provided by the damp marine sponge compressed by a snug bandage. Later when the sponge dries, it stiffens and gives considerable fixation. When the graft is sutured in on a stretch, convex surfaces with a smooth base do not always need a pressure dressing. (7) Later, after the graft has grown to the underlying bed, any superficial infection should have a type of dressing which promotes adequate drainage and tends to inhibit bacterial multiplication. Gauze saturated in one of the mild antiseptic solutions is indicated to give drainage.

The Operation for Releasing a Cicatricial Contracture

In correcting the limitation of function which a cicatricial contracture may cause (Fig. 42), not only should one crosscut the limiting cicatrix but all of the hard scar in the base should be removed if possible. The tissues should be placed in position of overcorrection. Excessive epithelized scar about the periphery of the denuded area should be removed so that the edges are loose and show no tension.

In old contractures, especially in children, the nerves and the blood vessels may have become somewhat shortened. Care must be taken not to overstretch a shortened nerve. Although one can stretch a nerve, it should be gradual. Twice this mistake was made in this series of patients. Once, the nerves to the forearm were overstretched when a limiting axillary scar and a limited scar at the elbow were corrected at the same time. Function largely returned over a period of six months. In another instance, a limiting popliteal scar was crosscut and the leg was placed in extension rather forcibly, resulting in a temporary paralysis which cleared up after a time.

The main artery to an extremity may be flattened by overstretching. One should be definitely aware of this danger when the patient is a growing child and the contracture is an old one. This is not likely to happen when a limiting scar is crosscut and the flexed finger is extended. To avoid interference with the

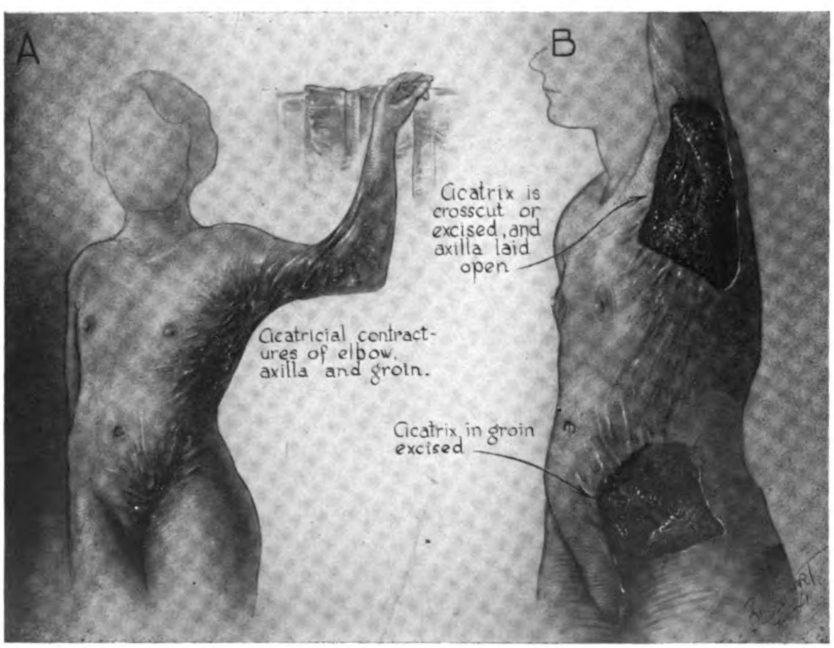


Fig. 42. (A) A child with a large limiting cicatrix of the axilla. This child also had a limiting cicatrix of the elbow region and the groin. (B) The cicatrix in the axilla has been crosscut and the limiting cicatricial bands removed. The cicatrix in the elbow region also has been cut. A skin graft 4 by 8 inches cut from the abdomen and another from over the thigh were removed with the dermatome to cover the denuded area which resulted after removal and crosscutting of the cicatrix.

circulation one should not cover the tip of the extremity with a dressing, and if in doubt, it may be well to nick the skin with a sharp knife. If red blood appears, the extremity is not in danger. When correcting a lesion of the finger, one should be careful not to cut both lateral arteries. All effort should be made to get good hemostasis.

Finally, a three quarter thickness skin graft is removed from some part of the body such as the abdomen or the thigh. The graft is then carefully stitched into the defect on a tension about that of normal skin. When the graft is not on the face, it is pierced here and there with a sharp pointed knife.

The Dressing

A dressing is applied consisting of a thin layer of gauze impregnated with a mild antiseptic ointment—usually 50 per cent xeroform ointment in vaseline. Silver foil next to the skin graft may be of value. Several layers of wet gauze follow next. For pressure, a wet marine sponge is next applied (Fig. 43). It is fixed by bandage or sutures so as to exert a rather firm even pressure on the graft. Finally, a wet cotton gauze pad is placed above the sponge and bandaged in place rather firmly. The sponge must not be bandaged so tightly that pressure necrosis is caused. This may happen if the background is a bony one. This original dressing is not removed until eight or ten days have passed. On removal of the dressing the stitches are taken out and a moist saline or boric gauze dressing is applied and changed, at least, daily.

Within the past few years Brown and Byars have started to use "mechanics waste" for

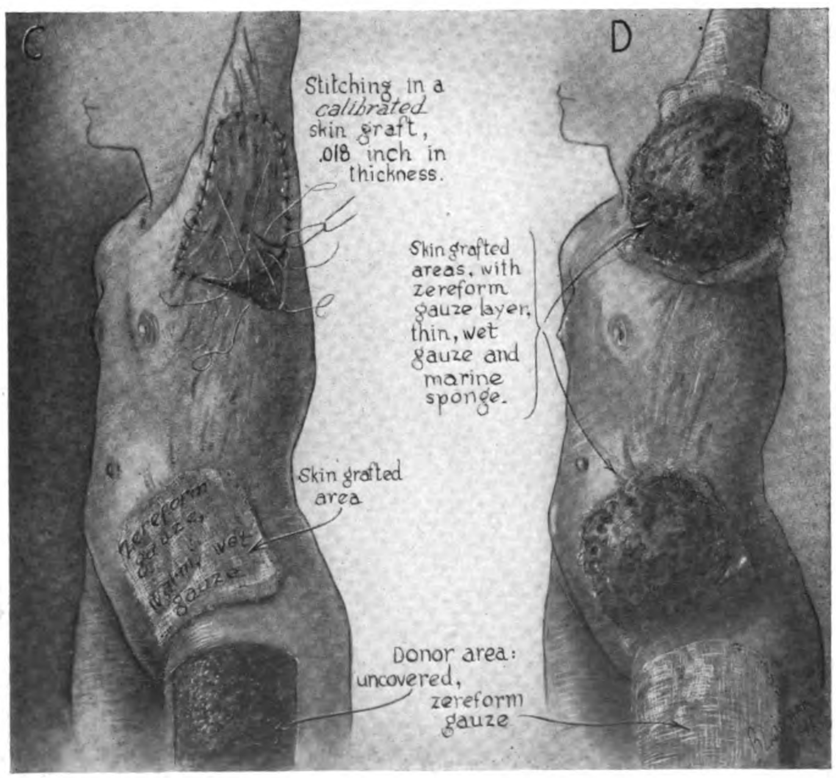


Fig. 43. (C) In this case a large calibrated deep intermediate skin graft was taken from the left thigh and one was also taken from the abdomen. The area in the groin which is shown covered with gauze has been skin grafted. In the axillary region the graft is being stitched into the denuded defect. After the graft is in place, small holes for drainage are cut in it. (D) The dressings are applied over the skin graft. They consist of one layer of xeroform gauze, and four layers of gauze saturated in normal saline solution, a marine sponge for purposes of pressure, a cotton gauze pad and a tight bandage. This dressing remains in place for 10 days or two weeks. The dressings for the donor area consist of one layer of xeroform gauze, four layers of plain gauze and a cotton pad. This is strapped down firmly with adhesive tape.

pressure over grafts, because of the expense and the necessity of large quantities of material. They believe "mechanics waste" properly applied in large quantities under a tight bandage is as good or better than marine sponges for maintaining pressure. In several clinics this is being used with complete satisfaction. A high class type of this waste is sold under the trade name of Wallcowaste.* This is more expensive than the ordinary waste obtained from a garage.

On a convex surface such as the forehead, which, also, has a hard even surface, it is possible to use only plain wet gauze next to greased gauze for pressure. On uneven surfaces and concave surfaces that lack a firm foundation, such as the front of the neck or the hand, large flat, damp marine sponges or garage waste are recommended as being the best dressing for purposes of fixation and immobilization.

The two main factors to which particular attention must be paid, if one is to be successful in obtaining a "take" after the application of a thick skin graft, are uniform pressure and fixation of both the base and the graft. It is pertinent, consequently, to make some further comments on the types of dressings which further this goal. (See Chapter VII, Page 137.)

Many primary dressings, besides the ones we have described, have been from time to time recommended for a dressing after skin grafting. Davis in his book described several, and Collier (1925) has spoken of paraffin, which was used during the war as a primary dressing. The dressings previously described come nearer fulfilling the objectives required than the others.

* C. Gilbert Wallworth and Co., Distributor, Philadelphia, Pennsylvania.

After the suture of a wound or a skin grafting operation on an extremity, it is almost routine with us to use some type of splint for fixation. Usually a simple board splint well padded is sufficient, and generally, adhesive strips are used to hold the respective members in position. When no skin covered space is left, as when grafting near the tip of the finger, the digit may be transfixed to the board with a small nail, or sometimes may be transfixed with a small wire stirrup to which a rubber traction that extends and fixes the finger to a banjo like hoop for traction is attached (Fig. 44). Often when the fingers are stiff, a double action traction is used. For two hours the fingers will be extended by traction, and for the next two hours flexed. Ace Adherent is of value to attach traction to an extremity, when the skin is not damaged. A cast is often applied to obtain hyperextension of some member, such as the arm, or after forcible change of position of an extremity, when it is deemed that the new position is not likely to be maintained unless fixation is definite.

Dressing of the Donor Area. The manner in which the donor area is cared for after the removal of a skin graft either superficial or deep, is of considerable importance. One layer of xeroform gauze is placed next to the denuded area. Directly on top of this is placed a gauze pad; pieces of dry gauze are allowed to barely overlap the edges of the area. The gauze

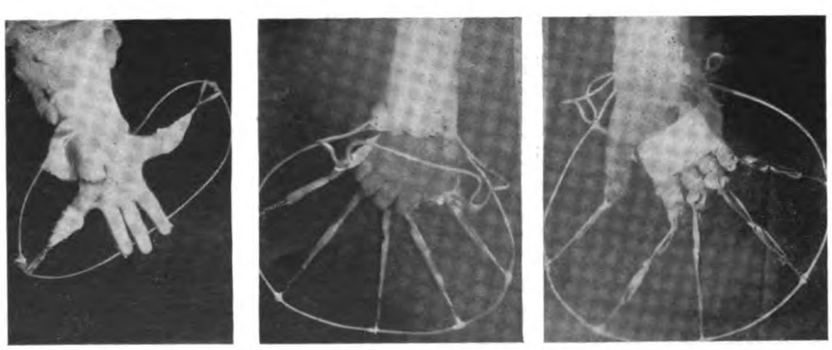


Fig. 44. Photographs of a plaster wire banjo splint with elastic traction, to get gradual extension.

pad is then strapped very securely in place with adhesive tape, so that the dressing cannot move or become displaced. On top of this is placed a bandage. The outer dressing, for purposes of cleanliness, is changed within a day or two. This inner gauze dressing is not removed before eight to ten days. By this time the epithelium will have largely regenerated beneath the gauze. If one attempts to remove these dressings after two or three days, it is uncomfortable for the patient. Daily dressing of such a denuded area is, also, very uncomfortable. The dressing should be firmly fixed for if the dressing is movable, the patient will complain of pain. Of course, if the wound becomes infected, it is well to soak the dressing off in a bath tub. A wet dressing is then placed over the area and it is treated as any other infected wound.

Dressing After Removal of the First Dressing. On removal of the first dressing after the application of a deep intermediate graft, ordinarily the "take" will be found to be complete without any blisters or blebs. About an additional week of dressing without pressure is usually advisable. Usually, we place one layer of ointment gauze next to the graft, followed by several layers of moist gauze. This in turn is covered with a cotton pad. This dressing is sometimes kept moist until the graft is entirely healed. However, if the "take" is perfect it may be allowed to dry. The dressing is changed on alternate days.

When the release of a contracture has been the reason for the grafting operation, an overcorrected position is maintained for several weeks if possible, and sometimes longer, if such seems advisable.

When one removes the first dressing, in about 50 per cent of the cases, after applying a full thickness skin graft, one will see superficial blisters. These are treated best in about the same manner that one treats a simple blister due to a burn, that is, let it rupture when it gets ready, provided the contained fluid is clear. If the fluid in the bleb becomes purulent, it should be opened immediately. As long as blebs are present it is wise to maintain pressure with the marine sponge.

What Happens to the Donor Area. Although the donor area will heal from the base when a skin graft is cut in the last quarter thickness of the skin, there is a tendency in certain individuals for some scarring. The thinner the graft is cut, the less scarring there is in the donor area. When the graft is cut thin, the area ultimately will appear a little whiter than the surrounding skin but it is as pliable and thin as normal skin. As a matter of fact, in some individuals when the graft is cut deep, the heaviness of the scar may suggest a keloid formation. To prevent this occurrence, a practice has been made of watching the donor area carefully. If the scar shows a tendency to become thick, irradiation is applied as a prophylactic measure in the same manner that one would use it to prevent a keloid.

The Return of Sensation

The time of the return of sensation has a clinical bearing, which may be quite important when a graft is applied to certain situations, as, for example, the fingers or the palm of the hand. It, also, has a bearing upon the amount and type of trauma that a skin graft can withstand.

Kredel and Evans, Davis and Kitlowski and Davis and McCarroll have studied the matter of the return of sensation. The first three papers reached the conclusion that temporary dissociation of recovery to pain and touch is demonstrated in all types of grafts, and is more prominent as the thickness increases. They concluded that regeneration of the ability to distinguish differences in temperature occurs sometime between the return of pain and touch sensation.

Furthermore, the return of sensation after transplantation of skin is not always complete even after many years, but often some return can be noted as early as five weeks. There is considerable difference and variation in the rate and extent of recovery. The thickness of the graft influences the rate, as does the amount of scar tissue and the state of the adjacent nerves. The return of sensation begins at the proximal and lateral borders, and spreads progressively over the graft.

McCarroll, who just recently has made a careful study of the return of sensation in cases of skin grafting done by Brown at the Shriner's Hospital, has reached conclusions contrary to those just mentioned. He states that, contrary to previous reports, he found that sensation returned over all parts of the graft simultaneously. He found too, that sensation returned in the thinner grafts earlier than in the thicker. In some split grafts, the return of the ability to distinguish painful stimulus and recognize light touch began to appear as early as 22 days after placement, and within 60 days or less the return was complete. Sensation in the full thickness graft returned somewhat more slowly.

We think that the reason the previous investigators drew erroneous conclusions was that they studied grafts in which the sensory nerve to the involved area had been cut, as occurs when one grafts the forehead having cut across the supraorbital nerve when raising a flap. If one studied a graft after such a procedure, the nerve supply will naturally return in a proximal manner because there is no way the nerve supply can return from the granulating bed, as the sensory nerve supply of the area has been cut at the original operative procedure.

Regeneration of the sympathetic control of the sudoriferous glands occurs late. From one year to one-and-a half years pass before sweating is noted, according to Kredel and Evans.

McCarroll did not attempt to reach a conclusion on the return of sensation to distinguish changes of temperature. He concludes that present methods of testing the skin itself were liable to be registered by the subepithelial nerves, and not nerves actually present in the graft.

Mucosal Grafts

One of the earliest attempts to transplant mucous membrane was made by Wolfe in 1872. He employed grafts of mucous membrane of rabbits for conjunctival defects.

As long ago as 1890 Djatschenko studied experimentally autografts of a mucous membrane taken from the lip and oral cavity. He applied them to conjunctival defects, and found that the histological changes were analogous to those described by Marchard for skin.

To obtain sufficient buccal mucosa to graft an area of any size, has so far proven well nigh impossible. At least we have had little success.

In one situation, nevertheless, it is absolutely essential that mucosa be used. When the eye is in the orbit and conjunctiva has been destroyed, if one uses ordinary epithelium, the cornea of the eye will be kept in a state of constant irritation and usually the skin will have to be removed. If one can get a mucosal graft of sufficient size to "take," the difficulty may be alleviated. Several times, we have successfully grown a mucosal graft of sufficient size to correct a relatively small deformity.

Not uncommonly seen is a similar type of lesion which requires mucosal lining. When the orbital cavity because of insufficient conjunctival lining is too small to hold an artificial eye, it would be ideal to add more mucosa by the application of a split stent graft. However, this skin with the conjunctiva produces with the tear secretion a cloudy fluid which often will make the glass eye appear unclean. Several times we have attempted to use a full thickness mucosal graft from the cheek, with the idea of solving the difficulty. So far our results have been only relatively satisfactory, and usually we were forced to use skin to line the contracted cavity. We have had the most success with full thickness mucosal grafts.

Technique of Mucosal Grafting

A full thickness mucosal graft is removed from inside the cheek just as one would remove a full thickness skin graft. As a general rule, this is considerably more difficult than the removal of a full thickness skin graft, so that one will simplify matters if he removes the mucosal graft along with some of the submucosal layer of tissue. After removal, the graft is placed upon a flat surface and stretched. With a pair of curved scissors, the excess subcutaneous tissue along with any of

the derma that can be removed, is cut from the graft. Then if one uses modeling composition for a stent and stretches the musoca over the stent very carefully, a good "take" of the full thickness mucosa can be obtained.

Usually in text books of plastic surgery, there is described a method of cutting a thin mucosal graft off of the lower lip, as one would cut a Thiersch graft or thin graft. When there is need of only the smallest amount of mucosa, such as the opthalmologist uses occasionally at the edges of the eyelids for entropion, this method may have certain advantages. But we have not found this a practicable measure for plastic procedures that require a greater amount of mucosa. Another area from which musoca has sometimes been obtained is the inner layer of the foreskin. We have never had any success with it.

When trying to build up the vermillion border on the lips, a graft will not be sufficient. Some arrangement, whereby a pedicled flap of mucosa can be turned across the lip, is the only procedure of any great value.

Dantrelle in 1932 discussed the uses and the technique of mucosal grafting and gives a rather complete bibliography.

Transplantation of Cutis or Derma

Otto Loewe, of St. Marks Hospital, Frankfort-on-Main is accredited with first making use of the cutis graft. In 1913 he reported his results in nine cases. Rehn reported a group of cases in 1914. In 1928 Uihlein checked 104 cases in which Rehn had utilized the dermal graft. During World War I von Eitner used the material extensively and in comparing it with free transplants of skin, fat and fascia, reported that the results of the use of derma were more permanent than the other materials. More recently Blair, Straasma and Peer have all used this material for purposes of filling out small deep defects.

The subepithelial layer of the skin is not difficult to transplant. The layer is principally made up of fibrous tissue. The fibrous tissue undoubtedly undergoes replacement by connective tissue from the host but the amount of atrophy is not so great as after the transplantation of fat. The histologic changes correspond to that about other transplants, such as fat. At first, there is evidence of degenerative changes, well marked round cell infiltration, with some evidence of replacement changes from resulting fibroblastic tissue.

Peer and Paddock recently have studied the histologic changes of human dermal grafts after they were buried from one week to a year. In spite of attempted removal of the epidermis some usually remains. "The remaining epidermis formed closed cyst cavities of microscopic size, containing horny material and fragments of hairs. In the later sections (seven months or one year) horny material was seen in the cavities of microscopic size surrounded by granulation tissue without epithelial lining. Sebaceous glands were noted only in the implants of one week's duration. Hair follicles were observed only in the implants buried up to three weeks, inclusive. Sweat glands were seen in all sections but in later sections they were in the process of degeneration and fibrous replacement. The granulation tissue which surrounded the implant was of the chronic type containing lymphocytes, microphages, epithelial cells, and often giant cells. In some cases with the formation of granulomatous nodules in the granulation tissue which surrounded the implant, and at times within the implant, bodies were observed within the giant cells and nodules. These bodies resembled hairs and fragments of hair."

For the elevation of small depressed scars like the scar of a pockmark, it is the only tissue with a real clinical merit. The factors which recommend the method, are the ease with which the material is obtained and the ease with which it is inserted beneath the scarred depression after it is carefully undermined. For the correction of a slightly larger contoural defect, it ordinarily has advantages over cartilage. It is easier to obtain and it does not curl as cartilage does. However, if the contoural defect is of considerable proportion, cartilage is superior, especially where some structural support is desirable. The advantage of derma over fat is that the result is about fifty per cent more permanent.

Recently, cutis has been used by several men somewhat for purposes of "guy ropes" and for added tensile strength to a wound such as hernia, or around an artery, or to replace dura in some cases. Cannaday has been convinced that the tissue when transplanted takes on the character of the surrounding tissue and he thinks that this type graft may be used in all cases in which fascia or tendon might be indicated. He feels that the tissue may be utilized with the expectation of better results because it heals more rapidly, has greater vitality, possesses greater tensile strength, has a good blood supply, and gradually assumes the function for which it is intended. In 1942, Cannaday recommended the use of cutis for the repair of certain types of incisional hernia and reported 37 cases in which he had used cutis grafts with satisfaction.

Technique: One removes the epithelium from over the derma to be used, as when removing a thin skin graft. Later the remaining derma is excised. Some of the underlying fat may be taken. The wound from which the derma is taken is closed. Through an incision made adjacent to the scar of the depression, the epithelium of the depression is undermined with a pair of pointed scissors. Sufficient derma is inserted into the cavity to elevate or slightly over-elevate the depression. The necessary number of stitches to close the incision are taken. The smaller the incision, the better. A pressure dressing is placed upon the operative area. Swenson and Harkins recommended obtaining the graft by the use of the dermatome and later the utilization of the epidermal portion of the graft for covering the donor area. Maingot reports that Rehn of Freiburg uses this same method.

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CHAPTER IV

TRANSPLANTATION OF BONE AND CARTILAGE

A. The Transplantation of Bone

The fate of the bone after transplantation has received greater consideration than that of cartilage from an experimental standpoint. The literature concerning bone transplantation is voluminous, but more questions remain to be answered with certainty than have been proven beyond argument. Two questions are particularly pertinent, when bone transplantation is to be considered. *First, which part of a bone graft survives on transplantation, and second, how and under what circumstances does bone form?*

The Osteoblastic Theory

Although Duhamel, nearly two hundred years ago, and later Goodwin (Mock), in 1800, first ascribed osteogenesis to the periosteum, the first work of importance concerning this question was done by Ollier in 1858. Ollier proved that bone can be transplanted without being extruded. He advocated the viewpoint that the graft remains viable in toto, because he thought that sometimes he observed an increase in the size of the graft. This was his test for true healing with retention of viability. The rôle which the periosteum plays in bone formation was, also, studied by Ollier. His belief that homogenous periosteal transplants do regenerate stands to-day disputed, but not disproved.

To-day the view point of Ollier is upheld by Axhausen, Lexer, Mayer and Wehner, Mock and many others. Contrarily, MacEwen, Dorrance and Ely contend that pure periosteal transplants do not regenerate, and that seemingly successful results are obtained due to the fact that bits of the cortex and the cambium layer are removed with the periosteum.

Radzimowsli and Bonome were the forerunners of Barth (1894) in presenting the viewpoint that with or without periosteum, a bone graft remains viable only temporarily. On the other hand, in 1908 Axhausen presented evidence that "living" periosteum is essential to the viability of a transplant, that the periosteum does not necessarily undergo necrosis, but that the bone graft itself degenerates and is then replaced. He maintained that progressive new bone formation is derived from the new periosteum, but he believed that only portions of the periosteum remain viable and proliferate. Furthermore, he maintained that the transplant should have a function to perform—be under mechanical strain—if it is to regenerate and maintain its form. About 1912 MacEwen presented still another conception of the biologic processes that follow bone grafting. MacEwen believed that the osteoblasts in the graft proliferate and lay down new bone, and that the rôle of the periosteum is solely that of a limiting membrane.

Baschkirzew and Petrow, in the same year of MacEwen's publication (1912), after some rather painstaking experimental work on the fate of bone grafts, concluded that periosteum and bone marrow are not essential for the regeneration of bone, that the chief source of the new formed bone is the layer of the tissue which envelops the transplant. They suggested that as the graft slowly degenerates, a physiochemical stimulus is given to the surrounding cells. Furthermore they concluded that most of the bone cells of the graft die, that the periosteum and endosteum undergo, at least, partial necrosis, and that there is no conclusive evidence that new bone is derived from periosteum or the endosteum, *but* in transplantation, periosteum does play a rôle as periosteal covered grafts heal in place more rapidly and show slower absorptive phenomena. Finally, they stated, that to a large extent, replacement of the graft by new bone depends upon the mechanical strain to which the graft is subjected.

Rohde in 1925, after an extensive series of experiments, came to the conclusion that, after excluding tissues and organs, bone building power is found only in specific bone building tissues, osteoblasts of the periosteum (cambium), marrow and endosteum, and that metaplastic bone building from the usual connective tissue of the musculature, the muscle septa, the tendons, the fascia, and the subcutaneous tissue does not take place. He attributes heterotrophic bone formation in soft tissue to the unused remaining mesenchymal cells, which through traumatism, infection, toxic stimuli or disturbance of the metabolism, may abandon their indifferent stage at any time and commence to build bone. The rôle of the marrow and endosteum in the formation of new bone was found by Rohde to be much smaller than the periosteum. He was led to believe that the cortex denuded of periosteum, marrow and endosteum did not take part in bone formation, and he concluded that if the circulatory supply is damaged or in the course of the regenerative process is destroyed, bone regeneration does not take place. Thus, Rohde concluded that "fundamental prerequisites for bone formation are living osteoblasts and unused remaining mesenchymal cells."

More recently Haldeman (1933) concluded that "Periosteum is the most important part of a bone graft in regard to union of the fractured bone and survival of the graft. In the absence of periosteum on the graft, union of the fracture is delayed or fails to occur, the graft dies and eventually is absorbed. Although the bone cells of the osteum die within a few days, the framework of the graft may then be revitalized by living cells spreading outward from the enlarged Haversian canals, a process which may be called "creeping substitution". In 1935, Phemister stated that the existence of a specialized osteoblast is supported by the greater tendency of bone to form from cells of the injured periosteum and marrow than from other connective tissue, and that it was proved definitely by the occurrence of ossification in the metastasis of an ossifying bone sarcoma located in tissue disconnected from bone such as skin.

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Such investigators as Mayer and Wehner, Brooks, Phemister, Thalhimer and Haldeman, and others agree that the cambium layer is undoubtedly of primary importance, as bone regeneration takes place in its presence, and this is true whether it is attached to periosteal or cortical transplants. Mayer and Wehner were unable to secure bone production from free periosteal transplants, but they thought this was due to the fact that the cambium could not be stripped from the cortex, nor could the osteoclasts be removed from the marrow in the Haversian canals.

The Mesenchymal Theory

On the other hand, in 1926, Leriche and Policard, after a series of investigations, concluded that "the periosteum does not cover an osteogenetic layer with osteoblasts. When the periosteum is modified by a change of circulation or only edema, it becomes then a ground for ossification. It is passively ossified—it does not make bone in an active manner." . . . . "The formation of bone is the result of the metaplastic change in the connective fundamental substance. This metaplasia takes place in three ways: (1) Transformation of the connective tissue by an edematous infiltration with a multiplication of connective fibrils; (2) infiltration by a special substance chemically undefined—the preosseous substance; (3) deposits of a calcerous mixture of calcium carbonate substance. Osseous metaplasia can occur in all types of connective tissue—embryonal type, fibrous type, etc."

In 1931 Watson, Jones and Roberts concluded that the osteoblast, as a cell, was not endowed with the specific power to lay down bone. They believe that only undifferentiated mesenchyme of the embryo forms a common mesoblastic stem, from which may develop fibrous tissue, cartilage or bone. Thus, they agree with the conception advocated by Leriche and Policard. They state that Robison has shown that tissue, which normally becomes the site of calcerous deposits, contains an enzyme phosphatase which hydrolyzes the ester and sets free inorganic phosphorus, and that the activity of the enzyme is dependent upon the hydrogen-ion concentration. When

the blood supply to bone is decreased, it undergoes calcification. The association of vascularity and phosphatase with calcification is reversible.

The Specific Stimulus Theory

Levander (1938) subsequently pointed out that the metaplastic theory has never been able to advance any reason for the transformation of connective tissue into bone tissue, but according to the osteoblastic theory, periosteum plays a dominating part in the regeneration of bone. However, according to his experimental evidence, it is only the periosteum of the growing skeleton that has power to stimulate the formation of bone. On the other hand, when fully differentiated hard bone tissue is grafted, new bone is always formed. Levander stripped the periosteum from bone and transplanted it into soft tissues, and concluded that the new bone is formed from the mesenchymal tissue in the areas surrounding the graft. He believes some substance is liberated from the graft, which acts as a specific stimulus to the mesenchymal tissue. He found that with alcoholic extracts from bones he was able to stimulate the formation of bone and cartilage at the site of injection in 22 per cent of his 70 experimental animals. For his control he used injections of pure alcohol and alcoholic extracts of other tissues. Spemann, also, has advanced a similar idea in regard to the embryonic development.

Resumé

At present, the majority of investigations on the subject of bone growth indicate that possibly the periosteum is the chief source of osteogenesis, but that endosteum, also, plays a part. Whether or not living cortex produces new bone is disputed. There is some evidence that the endosteal cells lining the haversian canals have a function in bone formation, as was especially pointed out by Brooks. Brooks, Mayer and Wehner, Mock, Ely and Campbell hold that the endosteum forms callous after fracture. McGaw and Harbin found that following the implantation of marrow, extraperiosteal defects are completely bridged by bone. If one accepts the theory of Leriche and Policard that in the presence of bone the mesenchyme develops the ability to form bone, the osteoblastic theory is not necessary. Levander's idea of a specific stimulus of a hormonal nature is an interesting conception on which more work should be done.

The question of viability of osteum is an interesting one to the reconstructive surgeon. Murphy (Mock) promulgated the conception that an autogeneous bone graft acts only as a bridge, and that the graft itself dies and is eventually replaced by new bone. Bancroft, Ely and Janeway held the opinion that osteum acts only as a framework upon which new bone is formed. In 1914 Phemister produced evidence that the dead portions of a bone graft are formed into living bone by a process of "creeping substitution," in which the periosteum principally but also the endosteum and the cells of the haversian canal of the graft play a part. Laelen, Frankenstein, Pakopilo, Lobenhoffer, Lexer and Axhausen thought that the bony part of the transplant was absorbed, but that the periosteum survived and laid down new bone. As to the mature osteoblasts of a transplant, Mayer and Wehner hold that they do not show proliferation. On the other hand, Axhausen, Brooks, Haas, and Phemister believe that a free bone transplant is a source of regeneration, and not merely a skeleton upon which new bone is laid down.

Histologic Changes After Bone Grafting

The histologic picture after transplantation of bone is fairly definite. First, a fibrinous exudate unites the surrounding tissue with the graft. This becomes organized and connective tissue is laid down. Degeneration of the graft and, also, replacement begins early. Union of the graft with adjacent bone takes place by means of callous. At the end of about three weeks, the surrounding tissues are firmly adherent to the grafts. Within three or four days, a periosteally covered transplant has an intimate union with the surrounding tissues. Blood vessel experiments show the periosteum filled with blood at the end of two days. When the transplant is not covered with periosteum, union with the surrounding tissue occurs less

rapidly, but after six days no great difference can be noted between the vascularization of grafts with or without periosteum. The cells of the periosteum soon show degenerative changes, but isolated islands of cells may retain their normal staining characteristics for a longer time. This fact has been interpreted by some as demonstrating the viability of some of the periosteum, and that it is the source of new bone formation.

Soon the cells of the graft begin to show nuclear changes, which gradually lead to their disappearance. This phenomena starts centrally in about three days. Evidence of absorption of the dead bone appears. The lacunae are filled with many large mononucleated and wandering cells. Absorption of bone takes place from the surface, in the haversian canals and in the bone marrow spaces. The entire bone becomes more porous. Hand in hand with absorptive phenomena, the process of substitution of dead bone with viable bone cells from osteoid tissue goes on. In some areas will be seen islands of new bone. In others infiltrated cellular connective tissue is prominent. Calcification starts as early as the fifth day. Cells called "osteoblasts" appear. Bone lamellae are laid down on the surface of the graft and about the haversian canals. Islands of cellular hyaline cartilage, also, are seen throughout the graft. The increase of new bone about keeps pace with the absorption of the dead bone. The vessels of the graft also undergo degeneration. Evidence of degeneration of the bone marrow appears in about two weeks. The cells lose their nuclei and are replaced by connective tissue. Eventually regeneration of the marrow begins. At the end of about five weeks this is fairly complete. It is believed that the regeneration of the marrow tissue is of hematopoietic origin. Judging from histologic findings, it may be concluded that the majority of a bone graft dies, and then is replaced by a process of substitution.

The cartilage of the bone grafts, bearing a complete epiphysis, degenerates at a less rapid rate of speed than the bone graft. Some believe the subperichondrial layer of cells retain their viability, as they do not show early degenerative changes. The ground substance, although it persists unchanged for some time, finally begins to show degenerative changes. Finally, new cells appear, which are thought by some observers to be derived from the remaining viable cartilage cells.

The Blood Supply of Bone

One factor of extreme importance in operations upon bone is a knowledge of the state of the circulation. Johnson studied the part played by each of the three nutrient systems of long bones. He concluded that the nutrient vessels, which supply the medulla and the inner half of the cortex, promote repair in the absence of the other two systems; and that the metaphyseal system supplying the same areas promotes slower but complete repair in the absence of the other two systems. This is particularly noticeable at the midshaft. He also concludes that the periosteal system, which nourishes the outer half of the cortex and periosteum, does not establish a collateral supply in the medulla in less than four weeks time, and in the absence of the other two systems produces poor healing of the cortical defects.

Pollock, Blaisdell, McKenny and Bancroft emphasize the point that a bone graft will live only if immediately surrounded by well-vascularized fibrous tissue. The success or failure of a bone plastic depends to a considerable extent upon the adequacy of the blood supply furnished by the host to the bone and surrounding tissues, from which the graft will receive nourishment.

General Clinical Indications and Contra-indications for Bone Transplantation

Bone loss due to injury is the important clinical field for the application of bone grafting, as is, also, the repair of un-united fractures. In the latter case the implanted bone offers a stimulus to osteogenesis that does not follow the use of inert substances. Pseudoarthrosis is best treated by a bone grafting operation. After the resection of tumors which necessitate the removal of a complete segment of bone, no other procedure compares in effectiveness with the insertion of a massive bone graft.

Bone grafting has been very effective when used for immobilization of tuberculous joints, such as the spinal joints or sacro-iliac joint, and on a lesser scale their use has been effective for the fixation of flail joints following poliomyelitis and other types of paralysis. The Koenig-Mueller operation for the repair of defects of the skull, which consists of fashioning a flap of scalp, aponeurosis, pericranium, and outer table of the skull adjacent to the defect, and turning it over the defect, has been fairly effective. Codivilla's operation consists of the turning of a periosteal flap back over the defect. It has not been so effective. The base tends to be absorbed. The transplantation of cartilage is more effective than bone for lesions of the forehead when the cosmetic result is of considerable importance. Although bone may be used to correct depression deformities, such as the so-called "saddle nose," at the present time most surgeons prefer cartilage to bone where filling material with some structural strength is the prime necessity. A bone graft tends to be absorbed to a greater extent than cartilage, and, in addition, the danger of failure to "take" is greater than is the case with cartilage.

The main contraindication to bone grafting is infection. The field for the recipient of the graft must be sterile and it should be dry. A blood clot about the graft is very inimical to success. Live fascia which heals in place is an admirable suture for fixation of the graft. If fascia is not used, absorbable sutures should be used in preference to a non-absorbable material.

Methods Employed in Bone Transplantation

The methods of bone transplantation include the full thickness inlay, the "barrel stave" outlay (Steele), the massive cortical onlay (Campbell and Henderson), the osteoperiosteal (Delangeniere), the periosteal, the medullary and sliding (Albee) grafts. All contain bone forming elements. The inlay and sliding grafts do not afford a very stable splint. When a splint is not needed, the osteoperiosteal or periosteal method may be of value.

The medullary graft should be condemned. Its principle is in opposition to normal bone physiology. Massive transplants are of value in the replacement of resected bone. To hold and fix the massive cortical outlay graft, Campbell uses autogeneous bone pegs; Henderson uses beef bone screws; and Key uses metal screws. Metal screws are advisable because of their superiority for purposes of stabilization.

Bone may be transplanted by means of a surrounding flap of soft tissues which maintain its blood supply. Such a procedure is sometimes used to repair a loss of the anterior part of the mandible, by use of a longitudinal section of the clavicle. A sliding transplantation from the body of the mandible may be slipped across a bony defect by the use of this principle. This method is not really a free transplantation or, in other words, a bone graft.

Delangeniere's graft is obtained by removing thin layers of bone with its periosteal covering by means of a sharp bevel edged chisel. Several overlapping thin sheets are then laid across the defect. Delangeniere claimed quite remarkable results for this method, 92 successes out of 93 cases, but other men have not reported such brilliant results. Absorption of the transplant and its replacement by fibrous tissue occurs sometimes. It has been noted that the longer the period of observation, the fewer the number of successes. During the war, the method was useful for bridging smaller defects of the inferior maxilla. Ivy reports that in the United States Army seventeen operations on the jaw bone were performed in the manner recommended by Delangeniere with 12 (70 per cent) successes.

For Albee's inlay graft a strip of bone of the desired thickness, width, and length is fashioned, usually from the tibia, and after freshening and bevelling the ends of the two bony fragments, the bone transplant is laid in the bevelled grooves across the defect (Fig. 45A). Albee's technique often is used for a sliding graft from one end of the bone into the other and to crosslap an old ununited fracture.

Removal of a whole rim of such a bone as the ilium, so that the shape of the segment

resembles the shape of the defect to be filled, is a useful procedure (Fig. 45B). For example, a new ramus angle and a part of the body of the lower jaw can be rather closely imitated in form by the removal and transplantation of the crest of the ilium. Also one can remove a complete section of such a bone as a rib along with its periosteum and, after sectioning it here and there half through, it can be bent to form a curve.

Homo and Heterotransplantation of Bone

Somewhat the same reasoning applies to discourage homo- and heterotransplantation of bone as applies to homo- and hetero- skin grafting operations. The graft, being a foreign body, causes the host to react to it as such. Rarely, reports of a bone graft being retained in the tissue in a manner similar to other inert tissues may be found in the literature, but eventually the non-viable graft is absorbed if it is not extruded. Cancellous bone is less resistant to homo- and hetero- reactions than a more compact tissue such as cartilage. Thus, after death and destruction of the soft tissue elements of the transplant, the hard formed elements of the bone act as a foreign body. (See the reaction after homo- and hetero- cartilage transplantation.)

Resumé

Present evidence indicates that most of a bone graft dies after transplantation. However, certain of the periosteal cells, endosteal cells and cells lining the haversian canals remain viable. From these cells a regeneration of the graft takes place, and new bone is laid down by a process of substitution. Replacement of the bone results chiefly when the graft is placed in contact with bone, and subjected to

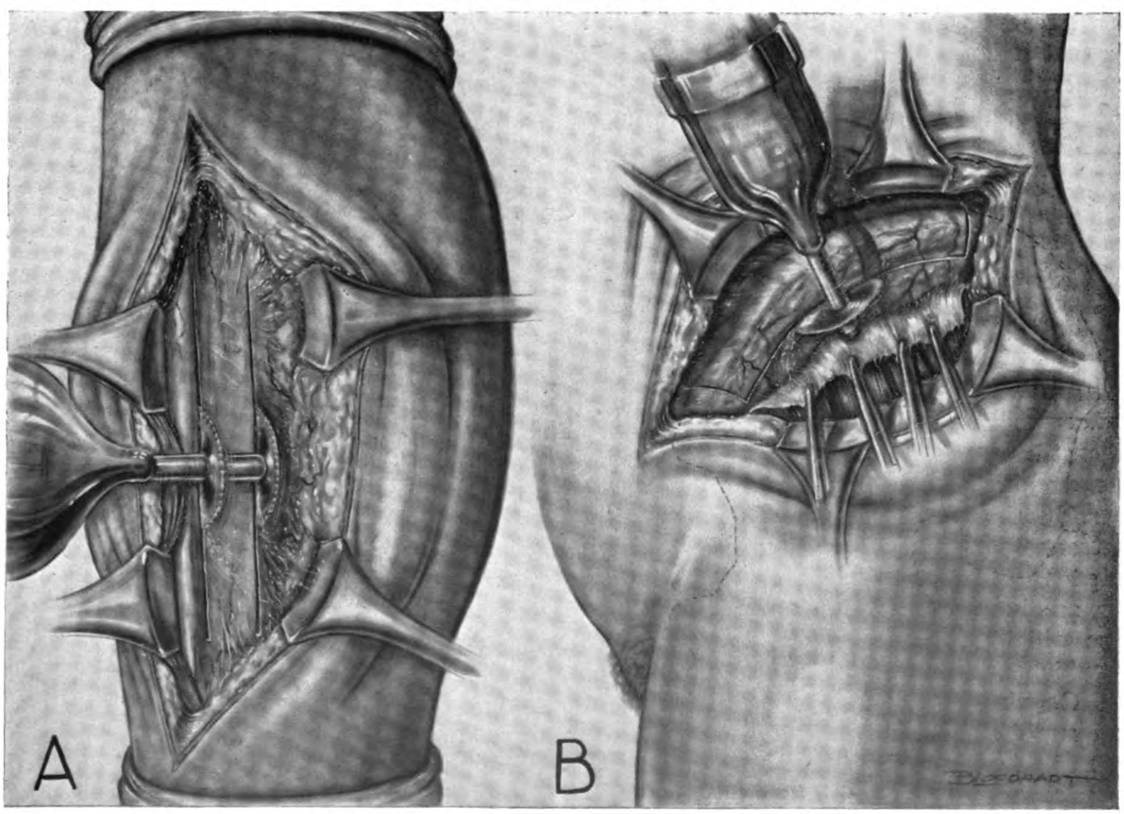

Fig. 45. (A) Method of obtaining a tibial graft with the Albee saw. The same method may be used for preparing a gutter for an inlay graft which is slid from one segment of an ununited fracture to the other fragment. (B) Method of obtaining a bone graft from the crest of the ilium.

stress and strain. In the absence of stress and strain, replacement may not occur. The osseous tissue for replacement is thought by many observers to be derived from those bone cells that are grafted and do not die; but others state that the new bone is derived partly from bone of the host and partly from metaplasia of undifferentiated connective tissue extending into and enveloping the transplant, and that presumably, some physio-chemical substance is released by the degenerating graft which appears to stimulate the formation of new bone. The argument still is carried on whether or not a specific bone forming cell exists. The majority of observers, however, believe that it does. Most observers believe that the periosteum is the essential tissue, which allows successful transplantation. The endosteum and the marrow are not of great importance. Some men (Neuhof) believe that the periosteum does not have persistent viability or any other function peculiar to it alone. However, the majority of observers believe that it does. There is early union of the transplanted periosteum to the surrounding tissue. This may be of some practical importtnce. The graft must persist until replacement occurs. *Success in bone grafting follows only after the transplantation of viable autogenous bone. Dead bone grafts and homo- and heterobone grafts are not successful.*

B. The Transplantation of Cartilage

In plastic surgery cartilage is transplanted quite commonly. Whether eventually the cells of a cartilage transplant gradually degenerate and are replaced is still a matter for argument. Generally the details of what happens after the transplantation of cartilage have been studied together with bone transplantation. There are, however, certain changes in the substance which are considerably different from that which occur after the transplantation of bone. Cartilage cells have a rather deficient blood supply normally and they seem to be able to live when surrounded by serum until the perichrondrium takes on a new blood supply, or if denuded, until surrounded by fibrous tissue attachments, the vessels of which contribute a lymph and blood supply. As after bone transplantation, the question of permanent viability of the transplant is of paramount interest to the reconstructive surgeon.

The Fate of Transplanted Cartilage

Paul Bert, who is accredited with being the first to transplant cartilage, came to the conclusion that the graft retained its viability and led to the formation of bone. Soon after, Zahn noted certain degenerative phenomena in cartilage grafts which he thought led to its eventual absorption. Fischer originated the theory that survival of the cartilaginous graft is dependent upon its perichondrium. Helfferich on microscopic examination of transplanted epiphyseal cartilage found central degeneration but the cellular structure of the surface was maintained. He thought the peripheral surrounding area became ossified. The first systematic microscopic studies of cartilage transplants were made by Seggel in 1904. He thought he observed a gradual degeneration of the graft with ossification. This, however, he did not find to be complete at the end of eighty days.

Davis in 1917 found that costal cartilage showed little or no signs of absorption after transplantation. The free end became rounded, but the total measurement changed little. The cells remained in good shape and showed well stained nuclei. So far as he was able to determine, the presence or absence of perichondrium makes little difference in the nourishment of the cells. His experiments were performed on dogs. The longest ran over a period of 576 days and 582 days respectively.

Santos (1932) states that "The experiments on cartilage grafts and investigations with regard to the healing processes in cartilage defects as a whole seem to warrant the following conclusions which are limited to hyaline cartilage covered with perichondrium: (1) the taking and survival of cartilage grafts is in direct proportion to the condition of preservation of the perichondrium; when the perichondrium is very carefully preserved the graft takes and survives for a long time without showing changes in histological structure. This property is more marked the less differentiated

the cartilage is and the more closely related it is biologically to the tissue into which it is grafted. (2) Fragments of cartilage deprived of perichondrium are quickly surrounded by a connective tissue capsule and absorbed. (3) Grafts in which the perichondrium and superficial layers of the cartilage have been injured undergo slow absorption. The cartilage tissue which is absorbed is replaced by proliferation of young cartilage which begins at the point where the perichondrium was injured."

This is contrary to the statement of Kolliker (1853) that cartilage possesses no power of regeneration and that wounds of cartilage do not mend by proliferation of cartilage. On the other hand, Neuhof (1923) stated definitely that in simple cartilage grafts, fibrillation starts after several months. A finely granular calcification appears at a later stage. Finally, there is a gradual death of the cartilage cells and eventually they disappear.

Rollo (1930) grafted cartilage in young and mature rabbits with and without perichondrium. Macroscopic and microscopic examinations were made at varying periods up to as long as two years after the transplantation. The experiments showed that cartilage grafted into the subcutaneous tissue dies, undergoing slow degeneration followed by some absorption, connective tissue substitution, or infiltration with calcium. These phenomena are retarded by the presence of the perichondrium, and take place considerably earlier in heterotransplants than in homotransplants. Rollo believes that reports of the permanent "taking" and proliferation of cartilage grafts are based entirely on observation of cells in the peripheral zones of the grafts, which are better nourished and protected by the perichondrium and, therefore, preserve their normal appearance longer than the other cells. He concludes, however, that the absorption and connective tissue substitution take place sufficiently slowly for cartilage to be employed as a material for prostheses in surgery.

Peer (1942) was convinced that "normal growth of all cartilage in structures in the body during childhood takes place from the deep layer of connective-tissue cells of the perichondrium. Growth also occurs by division of cartilage cells followed by the production of a matrix about each cell separating one from another. After adult life cartilage ceases to grow, and there is considerable doubt concerning its powers of regeneration following injury; the cartilage wound usually being filled in by connective tissue associated with little if any new cartilage formation."

Peer buried 15 autogenous cartilage grafts; rib septa and ear cartilages in eight infants or small children and removed the grafts after intervals of between one month and one to two years. He states: "A study of the measurements demonstrates that auricular and septal cartilage grafts showed an appreciable increase . . . but four rib grafts in the same individual showed no growth after two years and two months indicating an individual variation in the rate and amount of growth in the thicker cartilage. The average rate of increase in the thin grafts was about 2/32 of an inch in a period of two years. . . . On section all of these cartilage grafts showed normal appearing cartilage cells and matrix with a complete absence of invasion or absorption. Both the elastic ear cartilages and the hyaline septal and rib cartilages retained their characteristic structures." He concluded: "All forms of autogenous cartilage whether young or adult survive successful transplantation as living cartilage which is not subject to invasion or absorption."

In a case of ours, for whom we had occasion to remove a cartilage graft placed in the nose four years previously, the following picture was shown: "Sections show nothing but collagenous anuclear necrotic appearing hyaline fibrous tissue in which fat is buried and here and there a few degenerated, reddish brown, orange staining fragments are incorporated in this dense old hysaline scar. No true cartilage, however, is encountered. Old anuclear hyaline scar." (Helwig)

Kirkham removed a section of cartilage from a graft placed in the abdomen eleven years previously. In his section the cartilage cells are definitely those of cartilage. It would appear from this section that the cartilage has remained viable for eleven years. In a second

cartilage case, we had occasion to remove from the forehead a piece of cartilage transplanted eight years previously. The child was 12 years old when the cartilage was placed in the forehead to imitate the supraorbital ridge. In the photomicrograph the cartilage cells appear normal and viable (Fig. 46). We have another case in which an ear was built ten years previously. The framework was autogenous cartilage. The patient was 21 years of age when the ear was built. Only slight atrophy of the ear has occurred, and it seems to be mostly of the surrounding soft tissue. Peer also (1939) reported that "two late autogenous rib cartilage grafts buried four and one-half years and six years appeared as living cartilage."

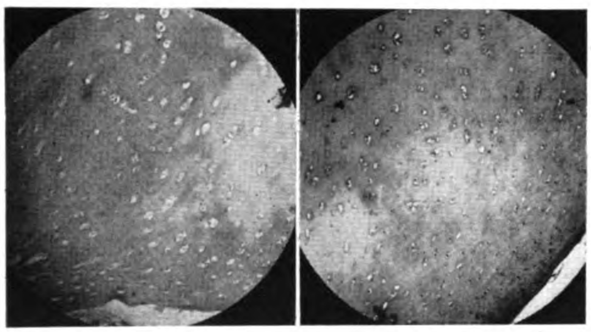

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Fig. 46. (A) Photomicrograph of a piece of cartilage which had been transplanted into the abdomen of a young woman 13 years before its removal. The cellular structure appears to be fairly normal and there was very little gross diminution in the size of the transplant. (B) Photomicrograph of a piece of cartilage removed from the forehead eight years after it had been placed there. The cartilage cells appear to be viable.

We are of the opinion that autogeneous cartilage in most cases retains its viability in the human. The tendency to calcification depends somewhat upon the individual and the age of the individual. The first case quoted was a prize fighter. He had had his costal cartilages fractured. At the fracture line they had healed by fibrosis with a deposition of lime salts in the fibrous tissue. It is not uncommon to find a deposition of lime salts in the costal cartilages after the age of forty years.

Nourishment of Cartilage

One often hears it stated that cartilage has no true blood supply—that it is entirely lymph nourished (Bames). On the other hand, Santos states that no lymph supply has been demonstrated for cartilage. This point is important in the question of the persistence of cartilage. Hurrell has studied this question and he has demonstrated that cartilage does have a limited blood supply. The perichondrium inflects inwards and carries with it vessels to an extent required for nutrition.

Microscopic Changes After Autogenous Transplantation of Cartilage

A simple cartilage graft the first two days after transplantation shows some fatty degeneration in the cells of the perichondrium. Other changes are not seen. The outer layers of the perichondrium degenerate and are replaced by connective tissue from the host. The inner layer of the perichondrium is not greatly changed. The matrix reacts normally to staining for many months. In certain grafts several years old, some fibrillation of the cartilage followed by a tendency to the appearance of a fine granular calcification may be seen. Rarely, after several years, the graft tends to be vascularized and replaced by fibrous tissue, but, in most instances, the cartilage cells apparently remain viable and show little or no change microscopically over a long period of years.

The ability of transplanted autogenous cartilage to retain its viability is probably due to the fact that cartilage has only a very limited blood supply normally, and that by imbibition of plasma viability is retained for a considerable length of time.

Homo- and Heterografts of Cartilage

Homocartilaginous transplants in animals, according to Loeb, are eventually replaced by fibrous tissue over a period of time. They react to a mild degree as a foreign body. After heterotransplantation of cartilage, the foreign body reaction is more intense, and replacement by fibrous tissue or even extrusion is more likely to occur than after autogenous by homogenous transplantation, according to Loeb.

Loeb states that in animals, directly around

the homotransplanted cartilage, there forms a thick layer of fibrous tissue infiltrated with lymphocytes, the cartilage itself remains largely preserved, although isolated parts may become necrotic. Lymphocytes and connective tissue have little power to penetrate cartilage. That cartilage usually appears to remain alive after homotransplantation, is due to the mechanical properties of the tissue which make it more resistant, he believes. The large cartilage cells which adjoin bone are less resistant and these usually perish after homotransplantation whereas, they may be preserved after autotransplantation. The leukocytic reaction about the graft is fairly intense in comparison with the lymphocytic reaction about a homocartilage transplant.

Preserved Cartilage

O'Connor and Pierce have been using preserved homogenous cartilage successfully in reconstruction of the ear in the human. Their cartilage was preserved in 1:4000 merthiosaline—a solution of 1 part aqueous merthiolate (1:1000) to four parts of sterile physiologic salt solution (Pierce and O'Connor). Clinically they have not found that they are absorbed.

Brown has discussed the possibility of what may or may not happen to preserved cartilage. He has shown patients in which the cartilage has been in place as long as three years. No data is given, however, as to the percentage of "takes" or length of time it remains viable. He presented it as "second choice substitution when for some reason the fresh homograft is unadvisable."

Peer has found that "pickled" cartilage (preserved in 50 per cent alcohol) after transplantation remains as a tolerated foreign body for as long as 9 months, after which time it is gradually absorbed. Some specimens at fourteen months and at two years showed areas of calcification and early bone formation.

In regard to the use of preserved cartilage in the repair of depressed noses and other facial depressions, Straith and Slaughter (1941) have concluded: "In view of the biologic rationale as brought out in the opening sections of this text and the encouraging results obtained in actual practice of the technique as reviewed, it seems quite logical to accept the use of homocartilage preserved in "merthiosaline" as the basis on which to restore facial contour. Homocartilage has the great advantage of eliminating the somewhat hazardous operation of costal resection with its prolonged incapacity and morbidity.

"As shown by a review of 100 consecutive cases in which homocartilage grafts were employed, 81 per cent were without complications while 94 per cent of the operations resulted in eventual success by the use of the described technique. Better results can hardly be expected with autogenous grafts, and certainly the use of no other foreign substance can compare with it."

Our results with preserved cartilage have not been so good as those of Straith and Slaughter. In at least one-third of the patients in whom fairly large pieces of artificial cartilage have been inserted, a part or all of the cartilage has undergone absorption without any immediate evidence of infection.

Recently (1939) Peer had reported that dead cartilage buried nine and one-half months to two years showed progressive invasion by fibrous tissue and partial absorption.

J. B. Brown at the Valley Forge Hospital has been using cartilage taken from fresh cadaver under aseptic conditions and placed in a container with "dry ice" and frozen until ready for insertion into the defect. There has been insufficient time for observation of this method to arrive at accurate estimate of the results of the method but at the time of communication Brown was enthusiastic. The method has the advantage of sterile preservation without the addition of some chemical which might be irritating to the tissues of the host.

Maternal Cartilage

Gillies first and later Kirkham and Greeley have used maternal cartilage of the external ear as a scaffolding to give support to the skin flap within which a new external ear is built. The cartilage seems to heal in well according

to reports. In 1943, at which time we reviewed the cases, it seemed to us that they had not been observed for a sufficient length of time to be certain whether or not there eventually will be absorption of the maternal cartilage or a foreign body reaction.

Clinical Application of Cartilage Transplantation

Cartilage grafting is one of the most useful procedures in plastic surgery. In the treatment of certain depression deformities of the nose, in the rebuilding of ears, and in the filling out of certain contoural defects of the face, cartilage transplantation has yielded brilliant results. A cartilage graft heals in place without much reaction. It will stand subsequent trauma. It can be cut sufficiently enough so that the form of the graft can be made that is desired. If cartilage is eventually replaced, the replacement is so very slow that from a practical standpoint the material is a very valuable one to more or less permanently fill a depression. In certain situations, as for the purpose of elevating the nose, cartilage may be used to give a certain amount of structural support. Costal cartilage is the most convenient source of cartilage when more than a very thin piece is needed. When only a thin piece is needed then cartilage from the ear and of the nasal septum may be utilized with advantage.

Costal cartilage tends to change from white to a yellowish color sometimes after forty years of age and to be partially calcified. This calcification may make shaping of the cartilage difficult, because one cannot cut it with a knife, and if a chisel is used, one is likely to fracture the cartilage. Thus, it may be necessary to use a saw as for cutting bone. Bames reports the dissolution of such a cartilage in men aged forty-eight and fifty-two. The cartilage was transplanted to the nose and disappeared after seven months and two years respectively. We have not seen this tendency to dissolution, although we have transplanted calcified cartilage several times.

The local sources of cartilage are: (1) The cartilages of the seventh, eighth and ninth ribs. They are the largest, most accessible cartilages, and adequate material for the filling out of quite a large defect may be obtained here. Occasionally the cartilage of the tenth rib may be sufficient. Other cartilages, which may be obtained from the septum or the auricle, may serve very well for filling in small defects, but cannot be used for structural support to any great extent. Bames states that these latter cartilages are blood nourished, and tend to degenerate somewhat more than costal cartilage and be replaced by fibrous tissue. On just what evidence this statement is based, we do not know.

Whether the perichondrium should be carefully preserved intact, or whether it should be equally carefully removed entirely, has been a much debated question. In so far as the immediate "take" of the transplant is concerned, it makes little difference whether the perichondrium is present or not. If the perichondrium is left on one side of a thin piece of cartilage, it will tend to warp with the concavity to the side of the cartilage. If all of the perichondrium is removed and the cartilage is cut too thin, cartilage tends to curl in an unpredictable fashion. The best protection against warping is a piece of some thickness as nearly surrounded by perichondrium as possible. When the perichondrium is entirely removed, we believe there is a slightly greater tendency for early decrease in the size of the implant. The presence of the perichondrium is often of help in preventing a slender implant from breaking, but its absence may make shaping a simpler procedure. The perichondrium is valuable in the interlinking of horizontal and vertical implants, when one is transplanting a right-angled cartilage to the nose.

When attempting to fill in a contoural defect in our work, we make it a practice to fashion a mold of modeling composition to gain an accurate idea of the size and shape of the defect. The cartilage is cut as nearly as possible to the size and shape of the modeling composition form. After it is cut to the proper shape, the cartilage is inserted into the cavity, and the skin and subcutaneous tissue are carefully stitched together above the cartilage. The

application of a firm pressure dressing to prevent the formation of a blood clot is essential.

Some men make a special effort to anchor and fix a cartilage transplant beneath the periosteum of any surrounding bone available. If possible, such a fixation may prove quite advantageous but often, the location of the graft will be such that this is not possible.

For the nose Bames states, however, that "interlinking is more easily obtained by fitting a projecting point of the columellar implant into a corresponding recess created in the bridge implant." This method we have used only a few times, but so far we have not had much success with accurate retention. In the nose there is a tendency for the strut implant to become displaced. Several times we used a suture of fine silk to hold the two ends of the cartilage in place, but we found that practically always when this was done, some infection occurred at the point where the silk had been placed. Consequently, removal of the silk was necessary and some absorption of the cartilage resulted. The method of using a bridge of perichondrium which allows one to place a right angle cartilage graft in the nose, as advocated by Gillies, has proven fairly satisfactory for us. Brown has recommended cutting the cartilage at right angles in the first place as being the most efficient way in which to handle the problem.

Technique of Cartilage Transplantation

Cartilage, unlike bone, can be trimmed and cut to any size or shape with a knife while, at the same time, it is sufficiently resistant to take the place of bony tissue in situations not requiring strength. Cartilage does not unite to bone but readily becomes attached to the surrounding soft tissues. If one studies the anatomy of the region of the seventh to tenth costal cartilages, quite a variety of shapes are offered or may be cut to pattern. Thin layers of cartilage may be obtained from the ear through a posterior incision. In the building of a nose practically always, besides the use of a flap for a lining or a covering, it is necessary to use cartilage to give contour and hold the shape of the tissue near to that of a normal nose. When the supraorbital region or the infraorbital prominence is destroyed by injury or infection, a good permanent imitation of the original can be constructed by implanting beneath the skin cartilage cut to a proper form. Forehead depressions, receding chins, and lack of prominence at the alar bases may all be satisfactorily corrected by this method. There is little likelihood of a blow damaging the reparation.

Technique of Obtaining Cartilage from the Chest. Usually the cartilage is removed from the right side and from the eighth to tenth costal cartilage (Fig. 47). The cartilage most appropriate in shape is selected. By sharp dissection the cartilage is isolated, cut and removed. The chest wound is closed as one would close an abdominal wound, in layers without drainage, unless the dead space left behind is considerable or hemostasis imperfect.

The depression to be filled in is undermined with scissors, or a knife through as small an incision as possible. Whenever possible, the incision is so placed that the implanted cartilage does not fall directly under it. After the skin and subcutaneous tissue have been undermined sufficiently, the cartilage graft is inserted into its prepared bed. During all steps of the operation, the utmost attention is paid to asepsis. Whenever possible, it is best to use a "no touch" technic. After the cartilage is transplanted in its bed, the wound is closed in layers with silk. One should attempt not to have a suture directly in contact with the cartilage. After squeezing all of the fluid from around the cartilage, to prevent the accumulation of serum or a blood clot, a damp gauze pressure dressing is applied for the first twenty-four hours. With good technic, in over 95 per cent of the cases, one is certain of the graft growing into its new bed without trouble. All is not lost if there is some infection about the graft. In several cases we have been able to save most of the cartilage, even after a low-grade infection occurred. Some years ago when infection occurred, we removed the cartilage immediately. Now by a stab wound we provide drainage without much liquefaction of the graft.

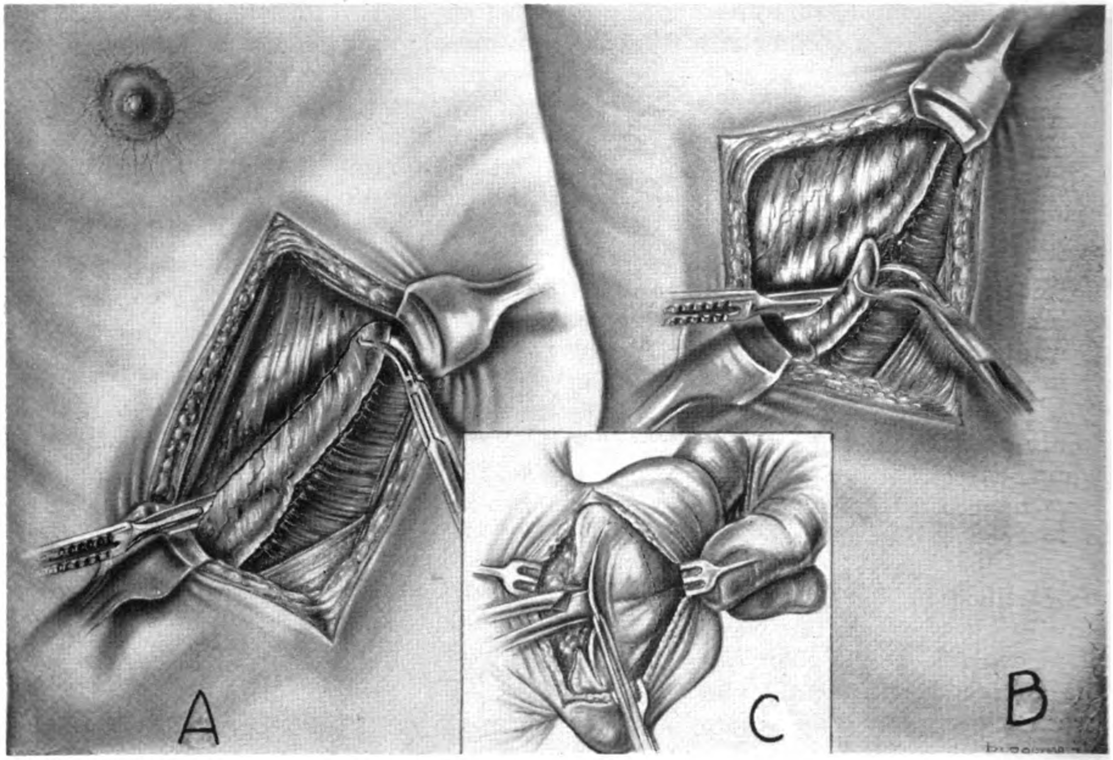

Fig. 47. Methods of obtaining cartilage. (A) Incision and exposure for removal of a piece of cartilage from the eighth costal cartilage. In this case a vertical incision has been made. One selects the cartilage according to the shape needed. (B) The oblique incision runs parallel to the nerves, thus the risk of injury to them is reduced. Ordinarily an oblique incision when one of the smaller cartilages is sufficient; when a large cartilage is needed a vertical incision is used. (C) To obtain cartilage from the ear, the exposure shown is used. An incision is made posterior to the ear. The ear is turned forward and the cartilage is dissected loose from the anterior sofe tissue. A thin, rather curved piece of cartilage is obtained. This does not deform the ear in any way. The operation may be done under local anesthesia with little or no discomfort to the patient.

Kelly has obtained his cartilage by a special gouge. He does not use the perichondrium.

Technique of Obtaining Cartilage from the Ear. Local anesthesia is used (Fig. 47C). The incision is made posteriorly in the groove between the external ear and the skin of the mastoid region. The ear is pulled forward. The areolar tissue is dissected from the cartilage. With a knife, the cartilage is cut through without cutting the anterior skin. With a sharp pair of pointed scissors, the cartilage of the concha is dissected free from the anterior skin. Only about one-half the thickness of the rather thick cartilage of the antihelix is removed. A piece of slightly disc-shaped thin cartilage about 2½ by 1 cm. in size can be obtained from the ear of an adult without eventual deformity being evident. After the cartilage is removed, the wound is closed with interrupted Lembert sutures and a pressure dressing is applied. This dressing need not be changed for four or five days. Then the sutures may be removed and, as a rule, no further dressing is necessary.

Technique of Obtaining Cartilage from the Nose. The technique of obtaining cartilage from the nose is that of a submucous resection operation, which need not be described here. It is described in all textbooks on diseases of the nose.

Method to Prevent Cartilage Grafts from Warping

Gordon New and J. B. Erich, have recently described a method of preventing cartilage

grafts from warping. They point out that finished grafts of fresh costal cartilage will not warp or become distorted if before use the cartilage is placed in a test tube containing water or aqueous sodium ethyl mercurithio-salicylate (merthiolate) and the tube is then placed upright in a beaker containing boiling water. Although the solution in the test tube will in time become hot, it will not boil and cause multiple ruptures in the cartilaginous matrix. The solution in the test tube will remain 3 or 4 C. below the boiling point of water for the ten minutes that the water in the beaker is allowed to boil. Cartilage which has been subjected to such a heating process will undergo a certain amount of warping while it is cooling; therefore it is to be cut to the desired shape after it has cooled. Furthermore, if the end of a cartilaginous implant is trimmed to a feather edge, the extremely thin margin may be remedied by cutting away that portion of the fine edge that is bent. When the cartilage is removed from the test tube, it is immersed for fifteen minutes in cold sterile physiologic solution of sodium chloride. With a few exceptions, the defect of the face can be fully prepared for reception of the implant by the time the treated cartilage has been made available for proper shaping. None of the cartilage implants that the authors have made by their method has undergone any distortion postoperatively.

A disadvantage of this procedure is that in the future it may be found that absorption occurs due to the fact that some or all of the cartilage cells are rendered non-viable.

Diced Cartilage Grafts

Lyndon Peer at the 1942 Meeting of the American Society of Plastic and Reconstructive Surgery described the use of some particles of autogenous cartilage for the purpose of filling in depressed deformities of the head and face. He stated: "About five years ago the thought occurred to me that the cartilage might be cut into many fine squares just as a cook dices carrots when preparing a salad. These fine cartilage squares could then be introduced into an exposed skull depression, gently patted into a rounded contour, and the scalp skin sutured over the rounded surface of the cartilage mass. I repaired a rather deep skull depression in this manner and was extremely pleased by the simplicity of the procedure and by the postoperative result.

"I have used this diced cartilage method in the repair of nine skull depressions during the past five years. The postoperative forehead contours in these nine cases have been much better than the forehead contours previously obtained with large segments of rib cartilage.

"Microscopic examination was made of the diced cartilage grafts at various intervals following transplantation. The sections demonstrated that the spaces between the small cartilage squares were occupied first by blood and later by ingrowing connective tissue, accompanied by numerous blood vessels. Each small square of cartilage rested against adjoining cartilage squares at some points, thus preventing contracture of the cartilage mass. The bulk of the diced cartilage grafts was increased by the addition of the numerous small spaces between the cartilage and for this reason, the diced cartilage squares actually filled a larger space than the solid rib cartilages from which they were cut. Autogenous diced rib cartilage grafts showed well-nourished cells, normal appearing matrix and a complete absence of invasion and absorption. Diced preserved cartilage grafts showed definite invasion and partial absorption of the cartilage.

"Diced cartilage grafts should be formed from the patient's own rib cartilage whenever possible. Living rib cartilage from a relative is second choice, and dead cadaver cartilage is third choice. One should use autogenous grafts especially in children because they have a long life-time expectancy and therefore require grafts which will last during their life span. Autogenous grafts are also indicated in children because of the growth possibilities of young cartilage grafts. Preserved cadaver cartilage or living isogenous cartilage may be used in older persons or in any case where the patient's general condition precludes the removal of his or her own rib cartilage."

C. Transplantation of Epiphyseal Cartilage and Joints

When Ollier in 1867 and Tizzoni at a later date noted that articular cartilage degenerated when transplanted subcutaneously, they concluded that the presence of synovial fluid was necessary to prevent this degeneration. In 1911 Tuffier reimplanted the head of the humerus and the functional result was good, but the persistence of cartilage was not demonstrated. Absorption of the cartilage of a joint surface would be what one would expect when one side of the cartilage lay against non-viable bone cells. Judet, after considerable experimentation in the transplantation of joints, attempted to prove that the success of such transplants depended upon the presence of the synovial membrane. Axhausen found that epiphyseal cartilage is replaced by fibrous tissue or is ossified and fails to function, as longitudinal growth of bone ceases after transplantation of epiphyseal cartilage.

In epiphyseal grafts, a widespread necrosis is seen in the marrow within a few days. Fibrous tissue replacement occurs. Finally the marrow is regenerated by hematopoietic action. In the cartilage of the epiphysis, the first evidence of degeneration occurs after about a month. The cells in the perichondrium decrease and the nuclei begin to stain faintly and disappear. Near the periphery there may be some signs of regeneration. The process is limited and the new cartilage is soon ossified. The osseous portion of the graft degenerates and is converted, for the most part, into a homogeneous non-cellular tissue, in which, later, evidence of regeneration appears in the form of bone deposition around the central portion. At the end of two months the epiphyseal line is obliterated.

Haas found that after transplantation of the articular end of bone, the epiphyseal bone does not grow after transplantation, but at the periphery there is some evidence of regeneration. He, also, found that in articular transplantation, the osseous part of the transplantation shows the usual processes of degeneration and regeneration characteristic of bone. The cortex lost its staining qualities, the marrow degenerated and the trabeculae were absorbed. Alteration in the articular cartilage takes place in the deeper layers of the articular cartilage, and, finally, in the more superficial layers. The change was slow and, at times, slight evidence of both degeneration and regeneration were present. Neuhof states that eventually there is a regeneration of the cartilage, which many observers attribute to certain cartilage cells retaining their viability, but he believes they are the outcome of metaplastic differentiation of the growing connective tissue of the host.

Joint cartilage in the past has been thought to show little sign of repair (Fischer, Redfern, and Haebler) in the central portion, but the lateral portion may show a fairly active reparative reaction, in which both the cartilage and the perichondrium participate. Recently, Santos has shown that this is not always the case. He reports several instances of cartilaginous regeneration in the femur; and he states that the microscopic picture seems to suggest very forcibly that the regeneration and proliferation of the old cartilage cells depend, to a great extent, upon secondary invasion and vascularization of the articular cartilage from the underlying marrow.

Clinical Application of the Transplantation of Epiphyseal Cartilage

Epiphyseal cartilage seems to be the least transplantable of all types of cartilage. It does not maintain its special function of producing growth in the length of the bone after transplantation. Clinically, it has no application.

Clinical Application for Transplantation of Joints

Lexer in 1907 made the first clinical application of whole joint transplantation. Half joint transplantation has had clinical application in operations for fracture dislocation, and some excellent results have been reported by Lexer, Perthes and von Haberer; but whole joint transplantation has had little or no clinical application. Lexer's experience in this field is the only experience worthy of mention. In his best known case, he used a resected knee joint homograft from a freshly ampu-

tated limb. The case was reported six years after operation. She has sufficient motion for locomotion. Roentgenogram examination showed absorptive changes and excessive overgrowth at the point of union of the graft and the bone of the host. Lexer made several other attempts to transplant a knee joint. Most of the attempts were unsuccessful or only successful to a limited degree. One of the greatest difficulties lay in the restoration of function of the extensor muscles. Other changes noted were fluid exudate, fibrous encapsulation, and changes resembling arthritis deformans.

Autoplasty is applicable in the replacement of finger joints from the toes. Thus, the possibility of the transplantation of joints has been established. It probably is not necessary to have replacement of articular cartilage by cartilage in order to obtain a satisfactory functional result. The question of the changes which occur after cartilage transplantation as it is now used to fill out a depression deformity, such as a saddle nose, is an entirely different question from that of the changes occurring in cartilage after free transplantation of a joint. Free cartilage is in contact with soft and connective tissue. Cartilage of a transplanted joint is in contact on one side with a non-viable bone. Although it is probable that a blood supply in the true sense is not immediately necessary to viability of cartilage cells, eventually a blood supply will be necessary if viability is to be retained. As the osteal part of transplanted bone does not retain its viability, the non-viable bone prevents nourishment of transplanted articular cartilage.

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CHAPTER V

TRANSPLANTATION OF FAT, FASCIA, TENDONS, AND NERVES

A. Fat Grafts

Neuber, in 1893, reported the first successful use of free grafts of fat in cosmetic operations about the orbit, and Silex, in 1896, obtained good results from transplantation of fat to fill up depressed scars. Again, in 1909, Verderame reported ten years experience in the use of fat for the purpose of filling depression defects. He recommended the use of larger transplants of fat than necessary to fill the defect at the time. In 1911, Lexer and his associates awakened further interest in the grafting of fat. Czerny (1895) transplanted a lipoma to fill defects and reported a satisfactory result. Since these earlier reports, fat grafts have been used for many purposes, such as filling of bone cavities, ankylosis of the joints, in brain surgery as a hemostatic agent, and in lung surgery as a means of compression. More recently, Neuhof (1937) has advocated the free transplantation of fat for the closure of bronchopulmonary cavities. He reports seventeen cases with eleven successes and three partial successes. Later, Lowsley of New York has been particularly active in emphasizing the hemostatic properties of fat for hemorrhage after operating on or after rupture of the kidney. But with all of these purposes, the use of fat has not attracted a wide recommendation.

Histologic Changes in Fat Grafts

It is doubtful if the ultimate fate of a fat graft is dependent upon the locality to which it is transplanted; but some have questioned whether or not the function, which it will be called upon to perform, may influence its final state. During the first two or three months the picture is dominated by degenerative phenomena. Certain of the fat cells show enlargement; others of them become smaller. Cysts are formed, some of which are multilocular. Fat globules are freed; these are partly absorbed and partly taken up by wandering cells. In the central part of the transplant, there are small areas of necrosis. The graft becomes infiltrated with small round cells. Peculiar larger cells (Wucherungzelle), with faintly staining protoplasm occupied by vacuoles, may line some of the empty fat cells. The fibrous septa increase greatly in size, and the entire transplant is surrounded by connective tissue. The septa, also, shows marked cellular infiltration. It has been stated by some observers that about the second month after transplantation of an autograft of fat, evidence of regeneration begins to be manifested, that the fat cyst becomes occupied with wandering cells, the wandering cells undergo changes into embryonal fat cells, and finally, the embryonal fat cells are converted gradually into adult fat cells. All observers agree that eventually the mass shrinks considerably, probably partly due to contraction of the fibrous tissue septa. At the end of five months the evidence of degeneration has nearly disappeared. Finally, some fat grafts are permeated by a loose, cellular, fibrous tissue, while others retain their fat. Thus, most of the fat cells of an autograft die and are replaced by fibrous tissue.

Recently Gurney, in an experimental study (185 adult white rats), pointed out some of the reactions of both autogenous and homogenous fat transplantation. In Group A, fat was transplanted in a single piece autogenetically without trauma. In Group B, the fat was transplanted autogenetically, but was cut into multiple pieces without other trauma. In Group C, autoplants were transplanted after severe trauma. Group D were homotransplanted without trauma. In Group E, autotransplants were transferred from the fat of the peritoneal cavity without trauma. The pertinent facts noted were: (A) without exception, those autografts which were transplanted as a single piece without trauma

retained their identity throughout the entire period of observation. The autotransplants cut into multiple pieces (B) and crushed. (C) survived a shorter period—disappearing within four months; (D) the homotransplants at the end of a three months period showed no evidence of the transplanted tissue. Microscopically, degenerative findings were seen in all.

The grafts transplanted in a single piece (A) showed the least degenerative changes. He states that a very definite but futile search was made to find new fat cells, which would lend support to the assertion that regeneration of fat is the rule after transplantation. All of the fat appearing in the graft as viable tissue was, however, composed of normal adult fat cells. At the end of one year about 90 per cent of the graft appeared to be normal. The peritoneal fat survives better than subcutaneous fat. Only about one-fourth to one-half of the transplanted fat survives. Finally, he concluded that at the end of one year following operation, the fat composing the graft is a portion of the original transplanted fat, and that most of the scar tissue found early in transplantation tends to disappear.

Homografts are not infrequently expelled even in the absence of suppuration. Homo or hetero grafting of fat is not considered a workable procedure.

Fat Transplantation in Clinical Surgery

Transplantation of fat may be particularly valuable in plastic surgery of the face to fill in a rather large cavity, which does or will result in a marked contoural defect. When, however, the defect is rather small, derma or cartilage, depending upon the location of the defect, will give a more satisfactory result. It must be remembered that fat transplants will atrophy as much as 50 per cent or more, while a dermal transplant will atrophy about 25 per cent; and a cartilage transplant changes as to size only very slowly over a period of years.

Originally fat was used by the opthalmologist, Barraquez (1901) to fill out the orbital cavity, but now in the orbit other more permanent tissues are generally thought to be more advisable.

Several times we have employed a large free fat transplant to obliterate a dead space after postoperative defect. After the removal of a large parotid tumor, fat may be employed in this manner with considerable advantage to fill the defect.

Makkas (1912) experimentally demonstrated that fat transplants heal satisfactorily into place in bone cavities. The clinical application of this procedure is handicapped because usually infection is present. Tuffier (1911) has introduced fat between the chest wall and the pleura for the purpose of obliterating tuberculous cavities of the lung. For tenolysis, fat often is provided previously by some sort of transplant so that some movement of the tendon will take place because of the "give" of a pliable tissue, such as fat. Among others, Rehn and Eden (1914) have conducted many experiments in the use of fat in both tenolysis and neurolysis. Lexer had the opportunity of observing fat transplant about a nerve suture. Four years later grossly adult fat was present. Murphy, in particular, and others reported good results after the use of fat transplants, free or pedicled, to prevent ankylosis after arthroplasty (see arthroplasty). The hemostatic action of fat is well-known. Off and on since Jobert's time (1823), fat has been used for this purpose. Lowsley (1933), has stressed the use of fat for the prevention of hemorrhage after rupture of such organs as the kidney, spleen and liver.

Technique of Fat Transplantation

A fat graft should be about one-half larger than the contoural defect to be corrected. For the success of transplantation of fat, three prerequisites are of prime importance. First, the cavity into which the fat is to be transplanted should be sterile. Second, hemostasis should be good. And third, adequate pressure is advantageous to give a certain degree of immobilization as well as being an aid to prevent dead spaces into which serum and blood may accumulate. Whenever possible, the incision through which the fat is inserted should not lie directly over the transplant but to one side, and the subcutaneous tissue should be carefully closed layer by layer before the skin is

closed. When the fat transplant is large, very often after about four weeks, a fluctuating point or two is liable to develop. On aspiration or incision an oily serum will be found to be present. If infection is not present, this only means that the central part of the fat, which was unable to develop a blood supply, has broken down. More shrinkage of the graft is to be expected if there is considerable central necrosis; but if the graft has been large enough, a good result will be obtained, as a rule, despite a certain amount of central necrosis.

In 1934 Cotton of Boston suggested a technique of fat transplantation, which he considers superior to the older technique. He states that when one places in a defect fat which is in one or two pieces, at first there is considerable reaction, and later there develops a tendency for concentric "balling up." This later factor interferes with smooth remolding. Therefore, he divides the fat into small bits before inserting it beneath the skin. In connection with this assertion, one should take into consideration the experimental work of Gurney which was quoted previously.

After any fat graft, a firm pressure dressing is advisable for a week or ten days. We ordinarily use a layer of gauze next to the skin and apply a wet marine sponge outside of the gauze. This dressing is left in place for a week or more if no evidence of wound contamination appears.

B. The Transplantation of Fascia

Kirschner (1909) made the first systematic study of the transplantation of fascia. Kirschner was particularly interested in replacing defects of tendons. Von Saar (1910) was the first to question the permanent viability of fascial transplants. Neuhof is of the opinion that Kornew's study (1913) can be accepted as the first satisfactory evidence of partial viability of autografts of fascia for fairly long periods.

Denk (1911) and later Neuhof came to the conclusion, from observation of experimental grafts, that the general architecture of fascia is preserved for six months to one year, but that eventually the transplant is replaced by fibrous tissue. Denk states that the new tissue laid down cannot be termed cicatricial or scar tissue, or the result of degeneration of the transplant, but it is more accurately described as a cellular tissue occupying the framework of and largely maintaining the form of the graft.

Gallie and LeMesurier (1924), before embarking upon certain clinical experiments, carried on a series of investigations on rabbits using patches of fascia, tendon and aponeurosis. They came to the conclusion that these connective tissues retain their viability when transplanted, with the exception of the central part of a thick tendon. Koch, Mason and Shearon (1932) reached conclusions somewhat similar to those of Gallie and LeMesurier.

The majority of observers have concluded that the greater part of autotransplanted fascia and tendons, and probably most of a sheet of transplanted fascia, ordinarily retain their viability. In a tendon of fair size the central part, at least, shows some degenerative and replacement changes.

Histology of Fascia

Fascia is made up of fibroblastic tissue cells containing elongated nuclei. Loose connective tissue intersperses the primary bundles. Each layer is joined to the other layer by loose connective tissues in which blood vessels and elastic fibers course. The elastic fibers are quite numerous and form a network which penetrates between the cells.

Gallie and LeMesurier found after transplantation of fibrous tissue, that during the first few weeks the ordinary phenomena of inflammation is shown. At first, there is an enlargement of the blood vessels and a surrounding plastic exudate. Soon a thin film of capillaries and fibroblasts surrounds the graft. This layer increases in thickness and finally develops into a mass of spindle-shaped cells and fibers. During this interval, the transplant remains alive and shows very little change beyond a moderate edema. After the third week, the inflammatory reaction gradually subsides. In specimens recovered as late as one year

after transplantation, there is nothing present microscopically to indicate that the cells and fibers have changed in any way, or that their physiological value has been influenced by transplantation. The exception to this statement occurs when thick pieces of tissue are transplanted. Necrosis is sometimes present in the deeper portions.

On the other hand, Neuhof states that the staining quality of the fascial cells is decreased rather early, and that unquestionably some of the cells degenerate. He admits that later there seems to be an apparent recession of degenerative phenomena. At this point, the question of persistent viability or gradual replacement of the graft by new cells becomes very difficult to determine.

Homo- and hetero-transplants are subject to antagonistic reactions between the host and donor, as previously discussed in relation to other tissues. The question of viability and replacement is a complicated one. Fascia is fibrous tissue. What the pathologist sees under a microscope is difficult to ascribe to a permanent cell or replacement cell. Many of the studies have not been made over a long enough period of time.

Clinical Application of Fascial Transplantation

Fascia lata offers a superior type of fascia for transplantation. Fascia lata is composed of three layers throughout most of its extent. The middle and most dense contains longitudinal fibers. The inner and outer layer lie at right angles to the middle layer of fibers. Fascia strips have considerable tensile strength. When transplanted fascia has only a minimal shrinkage.

Briefly, for purposes of description, the clinical applications may be grouped as follows: (1) To repair injuries to tendons, (2) injuries to ligaments, (3) for retention of certain fractures, (4) to aid in support in certain paralytic deformities, 5 ~~(6)~~ to support a ptosis of certain viscera, 6 ~~(7)~~ to give additional support in difficult hernias. There are various other miscellaneous uses for fascia (See specific operations in succeeding chapter).

(1) Injuries to Tendon and Muscles. Kirschner in 1909 advocated the use of grafts of fascia for tendon defects. More recently (1923) Neuhof has advised its use. Neuhof argues that fascia strips have certain advantages over tendon. He states that some degeneration of tendon is the rule and that fascia because of its flat surface tends to undergo minimal change. On the other hand, Mason and Shearon, Mayer and Bunnell prefer tendon to fascia for the repair of a tendon defects. The indication for fascial transplantation, after injuries to tendon and muscles, usually occurs in wounds of tendons in which the muscle has contracted and it is impossible to bring the muscle and tendon ends together. Most men consider free tendon transplantation as being superior to simple fascia interposition, when the defect is solely a tendonous one. However, Gallie and LeMesurier, contend that a fascia strand is as capable of giving a satisfactory clinical result as is tendon. In rupture of tendons subjected to great strains, as in repair of the ligamentum patellae, or the quadriceps tendon in ununited wounds of the tendo Achilles, repair by fascia is probably often the method of choice. (See Chaps. X and XXVIII.)

(2) Injuries to Capsular Ligaments. After rupture of capsular ligaments, firm healing does not always take place. An example is habitual dislocation of the patella, the lower jaw, or head of the humerus. By means of heavy strands of fascia or tendon, satisfactory prevention of recurrences has been the result. (See Chap. XXVIII.)

(3) Certain Fractures. Often when some fixation which will heal in situ is desirable, it is better to suture to fascia immediately such a fracture as that of the olecranon, or the patella, and certain other fractures, where a clean field is obtainable.

(4) Paralytic Deformity of the Body. Fascia strands to give additional support to a paralyzed muscle group, and to prevent a counter pull have been recommended by some men. One bony structure may be fixed to another with fascia strips. Paralysis, causing a winged scapula, offers such a field, as do many other conditions described in subsequent chapters.

(5) Paralysis of Certain Facial Muscles. Kirschner in 1910 used fascia to fix the upper eyelid to the frontalis muscle. (Chap. XIX). Kirschner (Neuhof) in 1900 first used fascial strips to fix the face in the correct position when at rest. Others have used the method before and since with satisfactory results (Chapter XVI).

(6) Visceroptosis. An operation for permanent fixation of the viscera is an uncertain procedure. Some of this uncertainty may be overcome if fascia strands are used for fixation. Floating kidney is amenable to fixation in one way or another with fascia. (See Chapter XXVI.) Sufficient fascia can be obtained from the back for this procedure.

(7) Hernia. Recurrence after closure of large ventral hernia, direct inguinal hernias and longitudinal oblique hernias are very frequent by the usual method of operation. Gallie has reported excellent results in 100 cases of hernia, in which he utilized a special technique which involves the interlacing of fascia. (See Chap. XXV.) Harrington has advocated the use of fascial strands in his technique for the repair of diaphragmatic hernia. He advocated a procedure which involves the principles laid down by Gallie.

(8) Other Miscellaneous Uses. Good results have been described after the use of transplants of fascia to correct an ankylosis of a joint. (See Chapter XXIX.) The most commonly used material for arthroplasty is the interposition of a double sheet of fascia lata.

Fascial grafts have been used to bridge a nerve gap and to surround the anastomosis, but there is no clinical evidence that the method is a feasible one. The transplant can only add to the amount of fibrous tissue surrounding the nerve anastomosis. If used for a tunnel, it only increases the scar tissue through which the outgrowing axis cylinder would have to penetrate to obtain a successful result.

According to Neuhof, for patching a defect in an arterial wall, fascial grafting may have a place in vascular surgery. He shows photomicrographs which indicate that the endothelium of the arterial wall will overgrow the fascial patch. Halsted once used a sheet of fascia about an aneurysm to prevent it from dilating, with only temporary success. Such procedures, even if practicable, rarely have but little clinical value. The problem of bridging defects of the hollow organs, such as the bladder, urethra, oesophagus, stomach, and intestine, and that of reinforcement of a questionable suture line is an entirely different one from transplanting fascia within the tissues. The question of infection is often involved. One side remains uncovered with tissue which might offer immediate nourishment. If it be true that fascia can be used for this purpose with success, nearly all of the general principles used in the transplanting of other tissues are violated. Konig and Hohmeier originally attempted the method in 1911. Neuhof's results (1923) were experimental and he did not recommend the procedure on the human unless it was used as one of last resort.

For a bladder defect, even when as much as one-half of the bladder wall was replaced by fascia (Neuhof), the outcome was successful. Perforation followed in only one instance and the functional result was good. Microscopic plaques of bone eventually developed at the site of the transplant. Copher repeated the experiments with regard to bone formation. He verified that bone did form. Neuhof, also, used this method for the closure of ureteral defects and oesophageal defects. In the former, the experiment was not successful, and in the latter, he reports success. No stenosis occurred after four weeks.

Such organs as the liver and spleen are very friable. It is difficult to close successfully a rent by means of the ordinary suture material. The suture cuts through and more hemorrhage results. If fascia is laid over the rent, and sutures are placed through the fascia and through the wall of the organ, the sutures may be prevented from cutting through the friable walls of the viscera. However, for the prevention of hemorrhage in the rent itself, a transplant of muscle or fat is to be recommended.

General Principles of the Technique of Fascia Transplantation

Gallie and Le Mesurier, in their experimental work, came to the conclusion that the

reason for failure with fascial transplants, usually, was due to the fact that fascia was held to other tissues by ordinary cicatricial tissue, which if subjected to severe strain, will stretch. Simple edge-to-edge sutures of fascia or aponeurosis to other tissues give the highest percentage of failure, and in applying fascia to bone they found that a long subperiosteal attachment was necessary. When the fascia or tendon was buried in a groove in the bone and preferably slit in several tails and stitched to the periosteum, generally it remained fixed. Nevertheless, even this method was not valuable as passing the transplant through a hole in the bone and, after splitting it, tying the tails together and transfixing the knot with some form of non-absorbable suture, which prevents slipping until healing occurs. Thus, they are convinced that the weak point in the old method of filling anatomical defects was the edge-to-edge suture of the transplant, with the surrounding tissues of the host. To obtain a good clinical result, it is necessary to cross-lap the edges freely. When necessary to cross-lap fascia fine interrupted silk was considered the preferable suture.

The method of choice, therefore, in fascia transplantation, for the purpose of filling in a defect needing structural strength, is to weave the suture across the defect in a lattice work fashion with wide insertion into sound tissue, or to place a specially modified sheet of fascia across the defect and hold it by sutures made from the sheet itself. Thus, the strain falls upon the suture itself and not upon the scar between the graft and the tissue of the host.

Gallie's modification of the old patch transplant utilizes this principle. The patch is cut out with a multitude of tails in line with the grain of the transplant. Each of these tails becomes a suture, and is woven into the surrounding tissues and tied with another. In doubtful situations, sutures are woven above or below the patch transplant to reinforce it. (See Chapter XXV.)

It is hardly necessary to emphasize the necessity for a sterile field and a dry field, and the use of fine permanent non-absorbable sutures to prevent the knots from slipping.

Techniques of Obtaining Fascia Lata

Fascia strips and sheets are ordinarily obtained from the fascia lata of the thigh. When a sheet is necessary, one must necessarily make a longitudinal incision and expose the fascia lata (Fig. 48); and if one wishes very fine strands, the longitudinal incision is preferable.

Mason has devised an instrument for obtaining wider strands of fascia lata, which obviates the necessity for a long incision, but it does not allow one to stitch the fascia lata together (Fig. 49). Herniation of the external thigh muscles seem to be no great handicap, however, and seems to largely correct itself in time. Ordinarily we have made a longitudinal incision to obtain fascia. By elevating the skin one can obtain tissue of greater length than the length of the incision.

C. Tendon Repair After Suturing and Free Transplantation

Paré, in the sixteenth century, was the first to speak of tendon suture but it was not until Haller, in the middle of the eighteenth century, demonstrated that tendons were insensible in contradistinction to nerves, that operative procedures began to be accepted. This process of tendon repair is said to have been studied first by John Hunter in 1767. The studies of Enderlen (1893) on the tendo Achilles of the guinea pig emphasized the importance of the tendon cells themselves in the repair of tendon. Marchand reviewed Enderlen's slides and concluded that most of the tissue in the reparation process came from the sheath and the surrounding connective tissue, but some of it came from the tendon cells. Borst (1903) made a critical study of the subject and substantiated Enderlen's viewpoint. He showed that the scar that fills the defect comes from the tendon, the peritendineum internum and externum, and the surrounding connective tissues. He found that the blood exudate that initially fills the gap was first infiltrated by polymorphonuclear leukocytes, later fibroblasts, and by the fourth day proliferating tendoblasts.

Next, the attention of investigators was directed towards the importance of function in

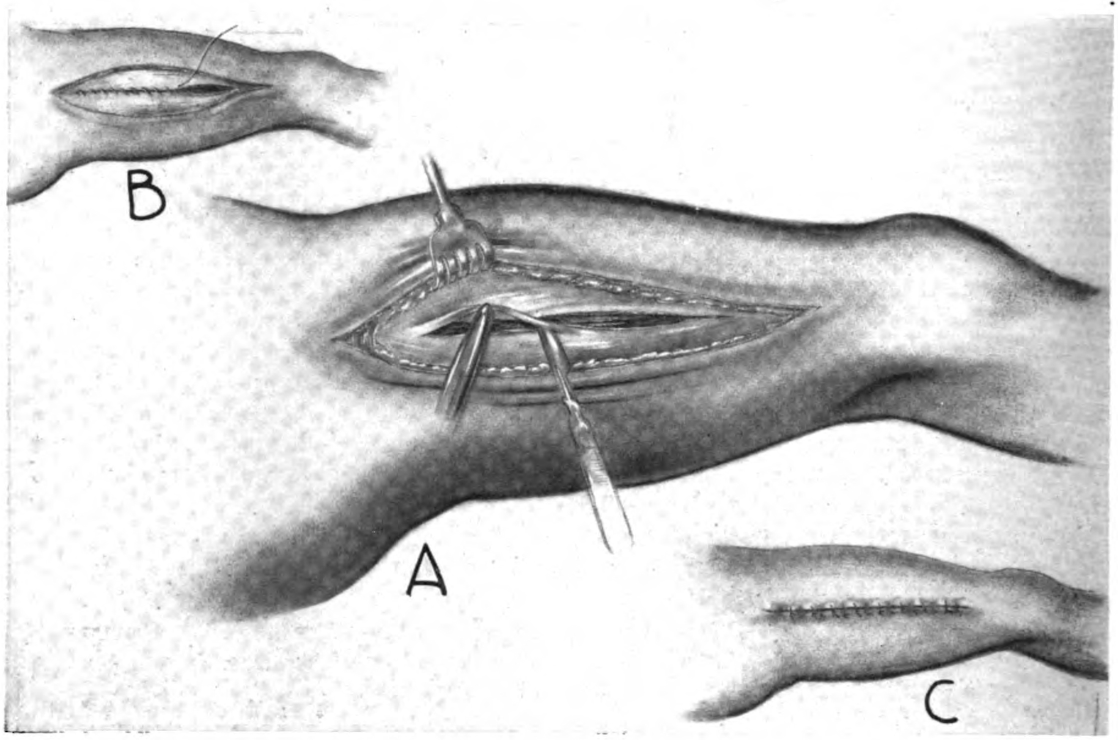

Fig. 48. One technique of obtaining fascial strands from fascia lata. (A) Shows fascial strands being cut with the "grain." (B) Shows closure of the fascia lata with a running suture. (C) Shows closure of the skin. By this method one may excise as much of the fascia as one wishes, or as much as there is present.

the healing of tendons and the significance of the sheath in the process. On the former question Kirschner and Rehn did considerable work. On the latter question Rehn, Wehner, Bier, Hueck, Schwartz and others made notable contributions.

Rehn concluded that a tendon graft without function underwent retrogressive changes and that if the graft were made to function, the graft remained viable. Moreover, that success in the grafting of tendons depends upon preservation of the external peritendineum, since this furnishes the tissue that molds the graft and stump together. The tendon sheath seemed to aid in early vascularization of the graft. Schwartz' study of the nature of tendon repair and growth is a classic. Besides working on sectioned tendons—sutured and not sutured—he conducted a series of experiments with grafts. He concluded that in tendon grafts, the regeneration is due to the transplanted external peritendineum that proliferates and establishes active vascular connections in the first few days and nourishes the graft. The tendon, he found, became partly necrotic although more peripheral parts remain viable. Hueck noted that even in tendons surrounded by a sheath, healing may occur if a good mesotendon is present. Tendon seems to heal by the proliferation of the peritendineum externum and internum, but in case the tendon is not enclosed in a sheath, the paratenon furnishes an abundance of tissue which has proliferative ability. In sheath covered tendons the synovial layer is as thin as the peritendineum internum; therefore, the tendency to union is decreased. Salomon suggested in this situation intravaginal suture with an inclosed sheath, of which parts were excised in order to allow the suture line to come in contact with subcutaneous tissues.

Imahasshi used vital staining methods and concluded that the healing of the defect is due to tendon cell proliferation. He thought by

this method he could distinguish tenoblasts from fibroblasts. The first cells he thought to fill the gap were fibroblasts from the surrounding tissue, but later this tissue was invaded by tenoblasts from the tendon stump.

Bloch and Bonnett, in a report on tendon surgery before the French Congress of Surgery in 1929, concluded that the tendon callus is mainly replacement tendon and not a true tendon, that the new formation can always be differentiated from the true tendon, and possibly, tendon cells may take only a very minor part in the callus formation. Mason and Shearon in 1932 published a report of experimental work on the dog. They concluded that union is effected first by proliferation of the sheath tissues, and that this union seems to reestablish continuity in a few days, but that after the fourth or fifth day, the tendon itself begins to proliferate and sends cells into the callus. They found that if the gap is not too great it might be bridged over in about two weeks. After the sheath has served its purposes of splinting the first union, it begins to become areolar tissue and, in a successful suture, eventually takes on its original function as a gliding tissue. From their study they concluded that cells from both the tendon and the surrounding connective tissue took part in the union.

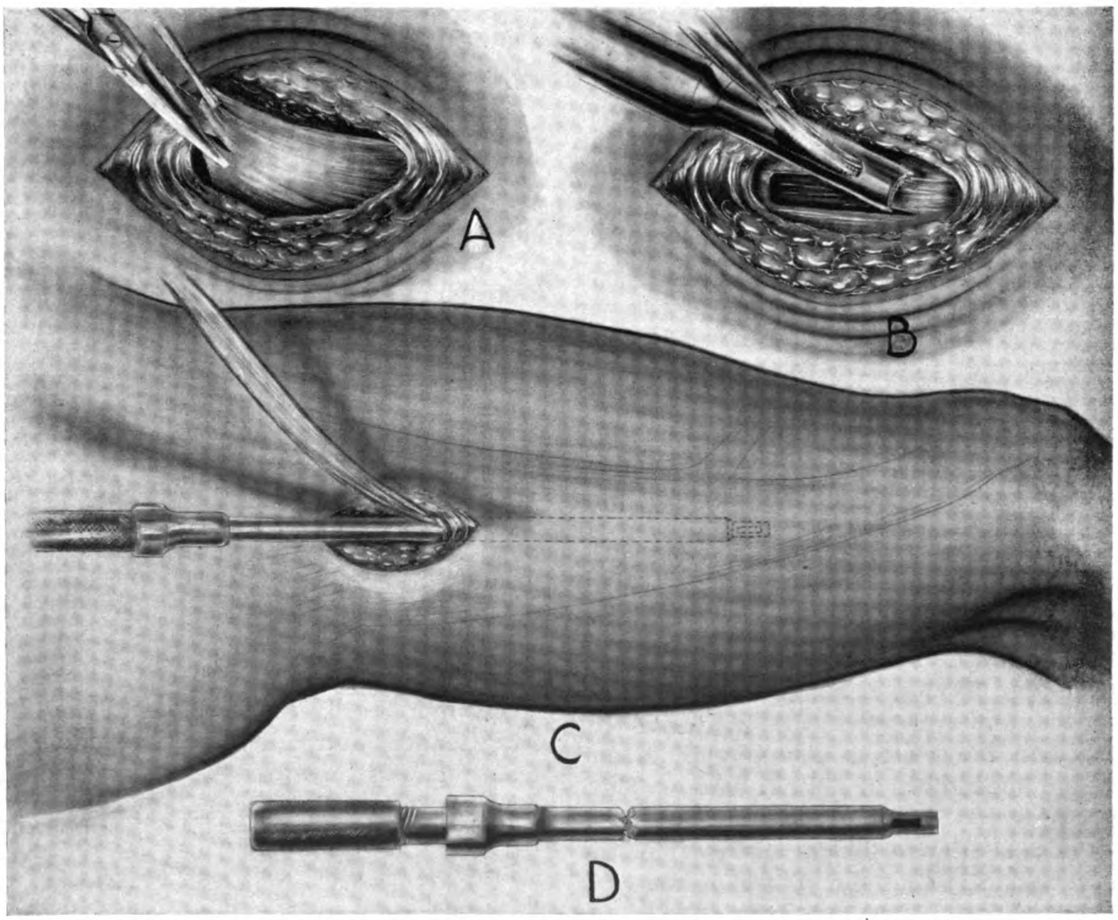

Fig. 49. Mason's technique of removal of fascia. (A) Fascia is picked up by scissors so that one may start the cutting tube down with the "grain" of the fascia. (B) Shows the fascia being drawn into the tube of the instrument. (C) The cutting tube of the instrument is being pushed down with the "grain" of the fascia. After the tube has been pushed down to the distal end of the fascia, the inside tube is removed, thus cutting off the strand of fascia. (D) The instrument for removing the fascial strands.

The Process of Repair in a Gap Bridged by a Tendon Graft

In Mason and Shearon's report the process of repair in a gap bridged by a tendon graft was studied. From the fourth to the seventh day there occurs a proliferation of sheath tissue from each end and the tendon tissue in the graft remains alive without showing evidence of proliferation. There is very little proliferation of the peritendineum internum of the graft. By the eighth day the stumps and graft are surrounded by a dense fibroblastic tissue, which cannot be separated from them. About the seventh day the tendon nuclei began to increase, particularly at the ends of the graft, and the stumps. The central part of the graft shows some areas of necrosis. From the eighth to the tenth day the process just described becomes more distinct. The effective union at this time is due to sheath tissue. Both the tendon and the sheath in particular show permeation with white blood cells. About the silk, the organization is somewhat disrupted. Between the twelfth to fourteenth day the proliferating tenoblasts push out, and if the gap between the stump and the graft end is not great there may be union between the tendon ends. The sheath tissue about the stump and the graft has become very vascular and strong by this time and the cells are becoming more adult in type. The end of the graft shows proliferating tenoblasts and the nuclei in the graft have become more numerous. During the fourth or fifth week the graft acquires strength and the tendon is covered with loose sheets of new sheath which allows it to glide some. At one hundred days it is not possible to determine the limits between the graft and the stump and the graft is assuming more and more the appearance of normal tendon. Thus, a process of healing occurs in autogenous tendon grafts similar to that of sutured tendons. The variation is that the sheath of the graft and the tendon graft remain viable in the greater part and both take part in the bridging of the gap between the separated stumps. Thus, Mason and Shearon concluded that the tendon graft remains more or less viable, is partially replaced by new tenoblasts and, finally, in the process of healing, that the tendon stumps, the tendon graft and the associated connective tissue all play their part and become important sources of material.

Mason and Shearon give the following resumé of the healing process after tendon grafting: "The process of healing of a tendon graft may be divided into two phases. During the first phase, which may be assigned to the first two weeks, the union between graft and stumps is effected by proliferation of the respective sheaths or peritendinous tissues. This phase represents the period during which the tendon is becoming more vascularized and is itself beginning to proliferate. The second phase overlaps the first and is one of tenoblastic proliferation. It begins about the fourth or fifth day after operation, i.e., at the time the first tendon mitoses are apparent. The effectiveness of the union due to the tendon participation depends on the amount of separation between the tendon and graft. Usually by the end of the second week the process is well under way and small defects are already bridged across by tenoblasts. From the second week on, the second phase becomes the more important so that the new tendon is formed essentially from the organization of a scar that lies between the ends of the graft and stumps and in the formation of which the tenoblasts themselves play the most important part. As the importance of the sheath as a uniting structure diminishes, it begins to take up the important function of serving as gliding tissue. During the fourth and fifth postoperative weeks, the sheath becomes progressively more easily separated from the organizing tendon, and with successful union there results a well organized tendon with a paratendon arrangement about it. A new synovial sheath has not been observed to form during the period of these experiments."

If this conception is accepted as being true the permanent viability of the graft would seem probable. In all likelihood, if tendon remains viable so does fascia, a conception which has been contested in the past.

The Importance of the Sheath and Peritendinous Tissues

In the comment on tendon repair which follows, the tendons on the volar surface of the fingers, inclosed in synovial sheaths with osteofibrous tunnels, are not included. To quote Mason and Shearon again: "The connective tissues surrounding the tendon, with the exception of the dense osteofibrous tunnels, are of the greatest importance in the repair of a tendon wound. They have the most intimate relation to the tendon, convey blood vessels and lymphatics to it, and permit easy gliding of the tendon. In the case of such tendons as the extensors on the dorsum of the hand or foot, as the Achilles tendon and few other paratenon covered tendons, the sheath tissues can provide for spontaneous repair, albeit often in a lengthened condition. Even where the sheath tissues are scanty, as, for example, in the synovial covered tendons, they are also important, but, depending on their amount, are less efficient than paratenon. For example, in the wrist the tendons are covered by a synovial sheath, and are provided with a rather large and continuous mesotenon that brings blood vessels and lymphatics to the tendons. Because of the number of tendons inclosed in one synovial layer, there is a good deal of connective tissue associated with the mesotenon and lying between the various reflections of the synovial sheet.

"While spontaneous repair at the wrist does not take place, operative repair, if correctly done, has a fairly good prognosis. The flexor tendons throughout their course on the fingers, however, have very scanty synovial sheaths. The visceral layer of the synovial sheath lies directly on the surface of the tendon, with very little, if any, connective tissue below it, and the parietal layer is likewise closely applied to the inner surface of the osteofibrous canal. The mesotenons of these tendons are reduced to tiny bridges, the vincula, which carry tiny blood vessels, possess little connective tissue and tear away from the tendon if any great pull is put on them. In tendons of this type, it is obvious that the sheath would be of little value in repair, and that here other methods of suture or surgical repair in contrast to the methods on the dorsum of the hand or in the wrist would have to be applied.

"As soon as a defect in a tendon results, the tendon ends retract a variable distance and the sheath tissues fall at once into the resulting gap. If the defect has been sutured, a similar, though usually smaller gap frequently occurs, and we have found it always to occur experimentally. . . . .

"In the case of a tendon graft the sheath tissue seems to take an important part in healing, comparable to repair by suture. The first tissue of a graft to show signs of proliferation and to effect union are the connective tissues surrounding it. As in the case of by suture, the gaps at either end of the graft are first bridged across by connective tissue resulting from the proliferation of the sheath about the stump and graft. This union serves to splint the graft in place until the tendons can directly unite by tendon cell proliferation. Therefore, in performing a tendon graft the graft should be left surrounded by its own carefully handled and preserved peritendinous tissues.

"These experiments have shown that tendon with its surrounding connective tissue maintains its vitality when transplanted as a free graft. The sheath very soon fuses with the sheath tissues of the two stumps, the tendon itself remains alive and soon proliferates and fuses with the stumps. In this manner actual tendon tissue bridges the defect. Although many surgeons have advocated the use of fascia or other connective tissue for tendon grafts, their position does not seem logical. A fascial tendon or a tendon formed about silk is, after all, scar tissue, and as such has all the defects of scar tissue—the danger of contracting or stretching."

Source of Supply

Grafts are easily obtained from the sublimis tendon and the palmaris longus. If the palmaris longus tendon plus its paratenon is used, it is necessary to make a large tendonal incision the full length of the graft. The long extensor tendon of the toes plus its paratenon in the dorsum of the foot can be taken without obtaining a toe drop as the extensor brevis

digitorum will serve to extend the toes. When a very long tendon is desired the extensor tendon to the second, the third and the fourth toes can be used. These tendons pass to and from the inner tendon of the extensor communis digitorum above the annular ligament at the ankle. They can be removed even above the annular ligament. The outer tendon of the muscle to the fifth toe, and the tendon of the muscle extensor digitorum brevis, and muscle extensoris hallucis longi and brevis prevent foot-drop. However, before these long tendons can be withdrawn it is necessary to strip off the paratenon. When the paratenon can not be removed with the graft, paratenon fat may be removed from some other site. After surrounding the tendon in a sleeve, the fat is implanted along with the graft. Paratenon fat differs from subcutaneous fat in being more elastic and pliable. A good place to obtain such fat is from about the triceps tendon at the elbow. Short tendon grafts may be threaded.

D. Tendon Switching

By tendon switching we refer not to the free transplantation of a tendon but to the transference of its point of insertion in such a way as to alter the function of a muscle. Nicoladoni in 1882 first advocated sewing the transplanted tendon to the paralyzed tendon. Biesalski utilized the sheath of the paralyzed tendon as a simple physiologic means of avoiding adhesions. The paralyzed tendon was withdrawn from the sheath and the transplanted tendon drawn through the sheath in its place. Mayer is authority for the statement that animal experiments have shown the correctness of Biesalski's method.

The technique of the methods of suture of tendons is taken up in (Chapter X, pages 204 to 206 and Chapter XXVIII, pages 799 to 819), as the same principles of suturing are followed in transplantation of tendons, severed tendons and in the reconstruction of lost tendon function.

Mayer states "that a physiological tendon operation must conform not only with the general surgical principles of absolute asepsis, minimum hemorrhage and minimum traumatism, but also with the following demands: (1) It must whenever possible restore the normal relationship between tendon and sheath. (2) The course of the tendon from its original site to that of the paralyzed tendon must run through tissue adapted to the gliding of the tendon. Injury to the periosteum or the crude boring of a hole through fascia or into osseus membrane is inconsistent with this demand. (3) The normal insertion of the tendon must be imitated wherever possible by implanting the living transplanted tendon directly with bone or cartilage, preferably at the insertion of the paralyzed tendon. (4) The normal tension of the transplanted tendon must be reestablished and the physiological length of the transplanted muscle thus maintained. (5) The line of traction of the transplanted tendon must be so as to enable it effectively to do the work of the paralyzed tendon."

The physiological operation may be summarized as follows: A long incision over the tendon to be transplanted. The sheath is opened. At least a part of the meso-tendon is preserved. The tendon to be transplanted is drawn into the sheath of the paralyzed tendon without removing the paralyzed tendon, after the sheath of the paralyzed tendon has been penetrated with a small probe. A probe with an eye is used to pull the transplanted tendon through the sheath of the paralyzed tendon. This is done with the aid of a suture stitched into the end of the nonparalyzed tendon so that the loop can later be utilized to draw the tendon downward. Mayer states that it is unnecessary to withdraw the paralyzed tendon from its sheath and cause unnecessary trauma. The sheath is large enough to encompass both the transplanted tendon and the paralyzed tendon. In the fixation of the transplant, Mayer showed that the proper tension was obtained if, when the patient was under narcosis, the tendon itself, as well as the muscle fibers were at zero tension. The implantation site is prepared by slitting lengthwise the paralyzed tendon and the periosteum distal to the point of attachment. The two halves of the periosteum are then laid back. The end of the transplanted tendon is then fastened securely between the two halves of the paralyzed tendon. The sutures are passed through the bone of

cartilage, ligament and fascia. As an additional reinforcement, the end of the paralyzed tendon is sutured over the transplanted tendon and, also, to the bone for about one inch. He states that the physiological principle is also applicable when no tendon sheath is present. In some instances the tendon may be run through subcutaneous tissue and in other cases the sheath may be transplanted for a short distance along with the tendon. Early post-operative exercise should begin immediately after the operation. Other fixation methods, such as drawing the tendon through the bone, are physiological and will meet the mechanical demands. Mayer believes that prolonged immobilization tends to the degeneration of a transplanted tendon. In one case of immobilization for twenty-four days, he found fat cells between the tendon bundles and elastic fibers in the epitenon. If the muscle is not allowed to function, it will degenerate after operation. An overstretched muscle tends to degenerate (Thomas, Jones, Mayer). The surgeon must be careful, therefore, not to overstretch the muscle.

Subsequent to tendon switching the tendon does not completely return to normal. Slight delicate connective tissue strands form between the tendon and the sheath, but they offer no hindrance to gliding. The loose fatty tissue investing the tendon—the paratenon—shows only slight changes. The fat cells are replaced by large cells containing two or more nuclei (Maximow, Marchand, Rehn and Mayer).

If the tendon is drawn through interosseous ligament or through a fascial septum, or if periosteum is injured, dense adhesions will form, which render function of the tendon impossible. Consequently, one has to pass the tendon through fascia instead of tearing a hole through the fascia. It should be carefully incised in order for a flap to be outlined which is inverted, so that the paratenon closes its deep surface. The inverted fascial tube, thus, may serve as a bridge for the passage of the tendon, and give it a gliding surface (Mayer).

In 1922, the question of the practicability of tendon transplantation was raised by the American Orthopedic Association. In the greater part of the cases in order to obtain satisfactory stability some operation upon the bones was necessary. It was their opinion that transplantation of tendons should be used only in connection with stabilizing operations upon the bones. By an ankylosing operation the lateral deformity of the foot may be corrected or prevented permanently, in order to have maximum function or freedom from pain.

E. Surgery of Nerves

In 1852 Waller clearly described the histologic degenerative changes which occur in the distal part of a severed nerve. With the development of the silver staining method, shortly after the beginning of the twentieth century, many observers very carefully studied this phenomena. It was found that the axons of the distal segment of the nerve degenerate and is absorbed, but the neurilemma remains and soon shows a hyperplastic reaction, which seems to aid in the downgrowth of the regenerative axis cylinders into the original neurilemma tunnels. The downgrowing axons apparently do not show any selectivity. Motor fibers may enter neurilemma sheaths formerly occupied by sensory fibers and vice versa. When such happens, probably functional regeneration is impossible, because of the specialized terminal nerve endings. The necessity for the presence of the neurilemma sheath, if regeneration of the axis cylinder is to occur, is to be emphasized.

Regeneration

Young in writing of functional regeneration states that: "Before that result is achieved a whole series of processes must occur; the processes may be divided as follows: (1) Closure of the gap between the severed stumps, mainly by the outgrowth of Schwann cells from the peripheral stump. (2) Retrograde degeneration of the cut central ends of the nerve fibres, and the sending out of many fine branches. (3) The progress of the tips of the axons from the central stump across the scar to the peripheral stump. (4) Break-up of the axons and myelin in the peripheral stump and removal of their remains by macrophages. (5) Multiplication of the nuclei of the Schwann cells and increase

in the volume of their cytoplasm to make the Schwann-bands (bands of v. Bügner) which eventually fill the old sheaths. (6) Progress of the axon tips along the peripheral stump, spinning out new fibres behind them. (7) The arrival of the growing tips at an end organ and the making of an union with it. This union may at first be atypical, and we should include here the subsequent process of normalization. (8) The increase in diameter of the fibres originally laid down, their medullation, and any other processes which may be necessary before they can conduct such impulses as can produce effective function. These processes of adjustment may possibly include not only changes in the nerve fibres, their cells of origin and perhaps their central connections as a result of the new peripheral connections, but also the addition of subsequent fibres, led along into the periphery guided by contact with the successful fibres.

"The normal nerve fibre is a system able to propagate messages by virtue of its composition of concentric layers of substance. At the centre is the axoplasm, a complex mixture, probably of semi-fluid consistency and containing at least some long submicroscopic rodlets arranged parallel to the main axis of the fibre."

According to Pumphrey and Young, 1938, the diameter of the axon has an important influence on function, impulses moving faster in the larger axons. The axoplasm is bounded by a membrane, the axolema, it is presumed. This has never been convincingly demonstrated under the microscope, though Boveri and others have described an inner neurilemma.

Around the axon there is often a visible myelin sheath composed of "concentric sheets of protein interspersed between layers of lipoids" (Schmitt and Bear, 1939, p. 38). This layer is interrupted at intervals by the nodes of Ranvier and perhaps the incisures of Schmidt-Lanterman. The distance between the nodes increases with diameter (Hursch, 1939) and is probably an important characteristic of the functioning of the fibre. Pumphrey, Young, and Holmes also believe "the thickness of the myelin sheath may affect many of the fundamental properties of nerve, but there are as yet few controlled data in which medullation is considered apart from diameter". . . . "Certainly the presence of a thick myelin sheath increases the speed of conduction of impulses.

"The outer boundary of the myelin is usually said to be marked by the neurilemma or sheath of Schwann, but visual knowledge about this region is not satisfactory, and there is much obscurity about the terminology (see Munzer, 1939).

"In 1839 Schwann emphasized that this membrane was not fibrous but granular and 'a cell nucleus is here and there seen lying in the pale border which surrounds the white substance.' The relation of this membrane to the surrounding connective tissues give rise to controversy. The sheaths are known as the inner and outer endoneurium. The inner endoneurium consists of a network of argyrophil reticulin and the outer endoneurium is composed of collagenous longitudinal fibres (sheath of Kay and Retzius, 1873)."

According to Young "a nerve fibre, then, is a unit made up of these various substances, and able to carry nerve impulses. Nerve fibres are not all alike but differ especially in diameter, length of internode and thickness of medullation, these being the factors which control speed and maximum frequency of conduction."

In summary Young writes: "Successful nervous regeneration must therefore depend mainly on the chances provided for adequate numbers of the outgrowing fibres to establish connections resembling their original ones. For this purpose it is provided that very many nerve fibres shall sprout out from the central stump and be met by many strands of Schwann cells, reaching out across the scar and thus ready to lead them to the peripheral stump. The axon tips then progress down the nerve, many within each original tube, and some of them will connect with appropriate end-organs. Function will not return with the first arrival of fibres at the end-organ, but only when the full process of regeneration of nerve has been completed by increase in the

diameter of the fibres and their medullation. The rate and extent of the increase of fibre size probably depends on the outflow from the central fibre. Hence the diameter of the latter, and perhaps the number of branches which it has to feed, determine the course of regeneration. But the size of the Schwann tube of the peripheral stump also affects the maturation. Small tubes allow at best only a slow increase of diameter, so that the longer a nerve has atrophied the less effectively will it regenerate.

"The process of maturation, therefore sweeps down the nerve long after the advance of the axon tips, and at a slower rate than the latter. Function only recovers when and to the extent that a sufficient number of the fibres with appropriate connections have become thus functionally completed."

Surgical Repair

Largely our clinical knowledge of peripheral nerve surgery has come to us from the large number of nerve injuries which have occurred during the more recent wars. Ordinarily, in civilian practice one individual does not see a great number. When a complete section of a nerve results from a wound, the central and distal end separates somewhat depending upon the loss of tissue and the surrounding scar tissue formation. It is a well known fact that after severance the axis cylinder distal to the nerve cell degenerates. The axis cylinder of the proximal end grows toward the periphery, establishes connection with end organs and if any part of it is separated from its cell of origin, that portion degenerates. Although the neurilemma is not a structural unit of the central nervous system, the neurilemma is extremely important in a consideration of surgery of the peripheral nerves, as the neurilemma is necessary for regeneration. Bardeleben sponsored the conception that, although the nerves are made up of anastomosing bundles of fibers, the actual course of the fibers is a straight one from the plexus to the point of origin of a peripheral branch. Staffel, in 1910, stated that the nerve fibers of a peripheral nerve were a unit for that nerve at any given level. This view means that any disarrangement of the funiculi may impair the result of the surgical repair. This theory has been denied by many men who have found numerous internal plexuses within peripheral nerves, by which interfunicular connections are made. Nerves, such as the radial, median, ulnar, peroneal and tibial, however, have quite definite gross funicular arrangement. It is generally agreed, therefore, that in nerve suture, if possible, end-to-end anastomosis of the proper funiculi should be attempted.

Suggested Alternate Procedure When End-to-End Anastomosis Is Impossible

There are instances in which the loss of nerve has been so extensive that all efforts to effect end-to-end suture fails. Alternate surgical procedures suggested for the repair of these and defects in nerve trunks have been: (1) Nerve implants, (2) nerve flaps, (3) suture a' distance, (4) tubulization, (5) nerve crossing, (6) nerve grafts, and (7) tissue or metal cuffs.

Nerve Implants: In nerve implantation, the proximal end of the distal segments is placed in the substance of a normal nerve. In 1873 Letievant suggested the method, and in 1884 Hoffman advocated it strongly. But, recently, Stookey and Pollock and Davis have demonstrated that any functional return that occurs is due to nerve crossing and not to the implantation. There are no anatomical or physiological reasons for an interrupted neuro-axon entering an implanted distal segment. In the nerve flap operation, a flap of nerve is cut from the central or distal end and turned to bridge the defect. Letievant in 1872 proposed the method. Stookey again has reviewed the evidence for and against the procedure and has concluded that regeneration does not occur.

Suture a' distance: The suture a' distance was proposed by Assaky in 1886. The idea was to supply a scaffold along which the neuraxon could grow but clinical and experimental evidence gives no support as to the efficiency of the procedure. The dangers of a barrier of connective tissue is evident. Gluck experimented with a decalcified bone drain with the idea of forming an open channel between the separated nerve ends. Other types of tubular

structure, such as fascia, blood vessels, and tantalum have been used by others but the method has not had the backing of clinical and experimental evidence. The end result is interference with the blood supply at first, and later an increase of fibroblastic tissue between the separated nerve ends.

Crossed Nerves: In 1828 Flourens successfully crossed the median and radial nerves. When nerves of like function are crossed, regeneration will occur but that method necessitates throwing one nerve or a part of it out of function to cause a somewhat problematic and questionable cross function in another nerve. In certain situations the method is probably to be recommended but the application of this method must necessarily be very limited. We have used the method to give muscle tone several times in cases of paralysis of the facial nerve, and consider the operation indicated in early facial nerve paralysis. (See Chapter XXI.) The technique of nerve crossing is similar to direct end-to-end suture. The disadvantages of the method are obvious.

Nerve Grafts: Philipeau and Vulpeau (1869) were the first to use nerve grafts experimentally. Albert in 1885 is credited with the first effort to bridge a nerve defect by a transplanted nerve. The first successful nerve graft is reported by Mayo-Robson. In 1888 he transplanted twenty-five centimeters of the posterior tibial nerve from an amputated limb between the separated ends of the median nerve. Many others have tried the method. As Neuhof states, "in tracing the development of the subject, one is impressed by the fact that the earlier reports in the literature presented the most brilliant results, successes being less and less frequently described as time went on." The histological evidence as demonstrated by experiments of Huber in animals, indicate that nerve grafts may allow a return of function. He recommended autotransplants and preferably cable-autotransplants. The cable autotransplant now is considered to be inadvisable because of the fibroblastic proliferation between the "cables." The question of the type of nerve he considered unimportant as, also, the funicular arrangement of the transplant. Huber, also stated that he thought homotransplant as efficient as an autotransplant, although he recommended an autotransplant if possible.

Autotransplantation: The original impression was that an autotransplant remained viable. Since specific stains have been developed, more accurate criteria concerning viability has been established. So-called Wallerian degeneration of the axis cylinders occurs similar to that seen in the distal end of a nerve after severance. The Schwann cells survive and may proliferate. The conception behind the method is that a channel remains which favors the downgrowth of the new axis-cylinders. The question of whether or not the remainder of the nerve is eventually replaced is uncertain. Neuhof believes that fibrotic replacements is the result. He states that the replacement tissue is more loosely woven and that it follows the pattern of the transplant.

Young writes, "no thoroughly satisfactory means has been devised for bridging the large gaps in nerves which often have to be repaired, especially after injuries received in warfare. The clinical and experimental literature is so confused, especially by the use of inadequate standards for assessment of recovery, that it is difficult to draw conclusions even about some procedures which have received quite extensive trial. (See Sanders, 1942, for review of the literature.) There is reliable evidence that autografts composed of thin strands of cutaneous nerve can survive, become innervated and give good recoveries in man and animals. Such thin grafts have been used in surgery chiefly in the facial nerve (see Duel, 1933) and in the nerves of the hands (Bunnell and Boyes, 1939), in which situations there is no doubt of their success. Sanders and Young (1942) have shown that new fibres grow through autografts nearly as fast as through a normal peripheral stump, and there is no basis for the fear expressed by Davis and Cleveland (1934) of a delay at the lower junction. Further, Gutmann and Sanders (1942) found that autografts 2 cm. long placed in the peroneal nerve of the rabbit produce recoveries of motor function which are nearly as quick and successful as can be produced by simple suture." We believe that autotransplantation of nerve, if for more than a short distance as in the

facial canal, has no records showing clinical success. The axons do penetrate the graft for a short distance. In an autograft of some length the graft, however, degenerates and fibrosis occurs impeding the downgrowth of the axons. Even in a short nerve autograft the neuroma which forms on the proximal end of the severed nerve may develop before the axons grow distally and are blocked by the neuroma. Duel advanced the idea that it may be well to sever the auto transplant and allow Wallerian degeneration to occur before transplanting it. His idea is that the new axones can, thereby, enter the axis-cylinders of the transplant with less resistance. His work has been done on the facial nerve in particular.

"New fibres do not penetrate autografts more quickly if they have been predegenerated as advocated by Ballance and Duel (1932), following a suggestion of Cajal. The chief advantage conferred by predegeneration is probably that suggested by Bentley and Hill (1936), that the nerves become firmer and hence easier to handle and to place in position. However it has recently been shown by Abercrombie and Johnson (1942) that Schwann cells reach their maximum powers of emigration during the period between 15 and 25 days after severance of a nerve (see p. 364) and it is therefore possible that grafts taken during this period would make better unions than would fresh ones.

"The processes of breaking-up have been very thoroughly investigated (see Cajal, 1928; Nageotte, 1932; Weddell and Glees, 1941). The axon becomes irregular and fragments, and the myelin breaks up, first into a series of chambers, and then into the rows of round fatty granules which are so characteristic of degenerating nerve. The broken up pieces of axon and myelin are then gradually removed, mainly by the action of macrophages. Since the recognition of degeneration is of great importance for anatomical, pathological and experimental studies of nerves it would be of great value to have detailed knowledge of the time-limits of the various processes of break-up in man and animals. Changes may begin to occur in the axons from the first moment after section (Speidel, 1935) and nearly all are swollen and beginning to fragment after 12 hours, (Setterfield and Sutton, 1935; Weddell and Glees, 1941). The breaking up of the axons begins on the second day and Weddell and Glees (1941) report that all fibres show some abnormality 48 hours after section of the nerves in the ear of the rabbit. But the break-up continues for a long time."

Homografts: According to Davis, "in homotransplants the Schwann cells also disappear and, after a short interval the graft is replaced by connective tissue. The fibrosis tends to be considerably denser in homografts than in autografts. In heterografts the regeneration is not seen, as necrosis occurs within a week or so. The replacement tissue of homo and heterotransplants is denser than after autografts. After transplantation of preserved nerves such as Nageotte first proposed (alcohol, etc.), the tissue is most dense of all and results in an excessive amount of fibrotic tissue which gives great opposition to the downgrowth of the proliferating axis-cylinders. The majority of homogenous grafts show a heteromorphous structure, due to destruction of the original graft structure which follows the necrosis of the ectodermal and endoneural elements after transplantation. Neurotization of autogenous grafts is predominantly regular and parallel to the graft structure while in homogenous grafts the regenerating nerve fibers follow an irregular and deviating course. However, despite the large amount of regenerating nerve fibers lost in the epineurium of the suture lines and in the grafts of heteromorphous structure, the distal nerve segment often shows a satisfactory neurotization."

Recently, Bentley, Gutmann and Sanders have confirmed and amplified the findings of axis regeneration through homografts in experimental animals. Loyal Davis on the basis of this experimental work and from two patients operated upon in civil practice believes that "Fresh homogenous grafts equal in size to the injured nerve may be used successfully to repair large continuity defects in nerve trunks. To the contrary, Spurling, et al, working in the Neurosurgical section of the Walter Reed Hospital, after analyzing the functional results and the histological changes

in whole fresh homogenous nerve grafts placed in peripheral nerve defects subsequent to extensive gun shot wounds of the extremities came to the conclusion that there was no clinical evidence of nerve regeneration in homogenous transplants in man. Quote: "Failure of clinical regeneration and the gross microscopic changes accompanying such clinical failure have been reported and discussed in eight instances of the grafting of whole, fresh homogenous nerves in man. It is apparent that the nerve fibers of the host nerve can penetrate such engrafted segments in appreciable numbers. From an evaluation of the dense fibrotic reaction that concomitantly invades such grafts, it is clear that maturation of such nerve fibers is improbable. Although whole fresh homografts furnish an easily accessible source for human nerve grafting, their further clinical use must be decried."

Preserved Transplants: The use of preserved homogenous transplants has also received considerable attention and Weiss has used rehydrated frozen dried grafts, and Tarlov has used grafts preserved in serum at 5 degrees centigrade for forty-eight hours. Hetero preserved non-viable transplants have been tried by Dujarier, Francois, Nageotte, Huber, Verga and Jiuanu, but the evidence that they were of any value is questionable or nil.

Nerve Cuffs: Stimulated by the exigencies of war, several methods have been devised to avoid the suturing of the nerve. Young and Medawar in 1940 suggested the use of coagulable plasma with consistency of glue to replace sutures of severed nerves. They used tissue extract to fortify the clotting agent. Tarlov and Benjamin, later used autologous plasma with muscle extract. Tarlov reported the results in fourteen cases. Following the use of this method there has beeen insufficient time elapsed to adequately judge functional results at the time of publication but in six cases his results were satisfactory. Theoretically, this method should be ideal because of the absence of tension, however, the ability of the material to give sufficiently, permanent fixation until regeneration takes place, is questionable. Most men have found it necessary to give additional support to the clot by a silk or tantalum wire suture.

Klemme has used a somewhat similar method substituting an acacia mixture and a cuff of allantoid membrane. Weiss has used rehydrated dried frozen artery cuffs. Singer has used Fibrin film and plasma clot for end-to-end union of nerves, and Tarlov has used a tube of tantalum. These workers all report satisfactory experimental results with their respective methods. However, we are in agreement with Loyal Davis who believes that surrounding even fresh grafts with metallic sheaths or collagen cuffs will keep mesodermal tissue from proliferating and furnishing the necessary vascularization to the graft.

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CHAPTER VI

TRANSPLANTATION OF OTHER MISCELLANEOUS TISSUES AND ORGANS

A. The Transplantation of Muscle

Muscle as a free transplant has no particular clinical value except for its hemostatic properties. Zielonko in 1874 published the first work on the question of the transplantation of muscle. The muscle was transplanted into the lymph sac of a frog and rapidly necrosed. Magnus repeated these experiments and his specimens showed degeneration, absorption, and connective tissue replacement of the transplanted muscle. Volkman, also, verified the conclusions of Magnus. After Roux expounded his theory that the survival of all tissue was dependent upon function, Jores and Schmid transplanted muscle and stimulated it with a faradic current. They reported success, but later reports did not substantiate their conclusions. Hildebrandt left the nerve intact but the muscle did not survive.

Free muscle transplants die. Histological evidence of degeneration sets in within a few hours. The fibers become swollen and the striation disappears. The nuclei show degenerative changes. Round cell infiltration follows, and the graft is surrounded by granulation tissue. At the edge, a few of the fibers are well preserved for a considerable time. Finally, the transplant is absorbed and replaced by connective tissue. Outside of hemostatic purposes, muscle grafts have little clinical application.

Muscle Flaps

McNealy, Shapiro, Huard and Isenberger have made use of muscle flaps, either to aid or to repair wounds of large arteries. The muscle flap is rolled around the arteries and fixed by suture. Beck (1935) (Chap. XXIV) conceived the idea of improving the circulation of the heart muscle by throwing a flap of pectoral muscle over the depleted area of muscle. Muscle flaps of the latissimus dorsi have been suggested by Reinhoff and others, as a means of diverting the flow of lymph through a new channel to correct lymphoedema of the arm. Wangensteen has advocated the insertion of a flap of muscle from the intercostal bundle to aid in plugging a bronchial fistula. Muscle flaps have, also, been efficacious as an aid to closing both osteomyelitic cavities and empyema, in certain instances. The operation should be planned, so the nerve supply of the muscle will remain intact and thus prevent subsequent atrophy of the muscle (Chap. XXIV).

B. The Transplantation of Peritoneum

Von Hacker and his associates carried on rather comprehensive studies of the value of preserved peritoneal transplants. He used the tissue to cover dural defects. But later observers noted adhesions after its use. Kolaczik used fresh grafts. He found considerable primary degeneration, and finally complete fibrous tissue replacement occurred. No clinical indication for the transplantation of peritoneum by itself has been established. The use of an omental flap covered with peritoneum is a different question from that of free transplantation. *Omental flaps* are exceedingly useful in intra-abdominal surgery. (See Walter's procedure for closure of fistula between the bladder and the vagina, Chapter XXVI.)

C. The Transplantation of Blood Vessels

In 1896 Jaboulay and Briau attempted the experimental transplantation of arteries for the repair of arterial defects. In 1903 Hoepfner demonstrated that the circulation continued for a time, at least, through homografted arterial transplants as well as autografted transplants. Carrel and Guthrie developed a method of blood vessel suture, which made possible blood vessel transplantation. Experimentally, Carrel, Guthrie, Stich, Makkas and Downman all reached the conclusion that arterial trans-

plants may remain viable for from one to two years or even longer after transplantation. Later, Borst and Enderlen indicated that there is no histologic support for the view that transplants remained permanently viable. They proved that the supposedly original transplants actually change to fibrous tissue, so closely simulating the structure of the original graft that a false interpretation of the situation is easily made. Thus, the microscopic appearance of a transplanted artery is no criteria of the viability of the original transplanted cells. The histologic changes that occur in arterial autografts are summarized by Neuhof as follows: "Within a very short time after implantation (a day or less), edema of the endothelial cells exists, and minute thrombi are to be found at the lines of anastomosis. There is an invasion of the adventitia by wandering cells, and fibroblasts extend into this layer from the surrounding tissues of the host. The adventitia becomes a richly cellular layer with many new-formed capillaries derived from the adjacent tissue. Only limited evidences of regeneration are to be seen in the media, slow replacement of the elastica and muscle fibers by fibrous tissue being the typical picture. The intima becomes a fibrocellular layer in which the thrombi that have formed ultimately disappear. A layer of "endothelium" covers the free surface of the graft, but whether this represents regeneration from the endothelium of the graft, as is usually maintained, or surface connective tissue cells that have undergone metaplasia remains to be proven. The possibility of extension from the adjacent endothelium of the host cannot be overlooked. Regeneration of elastic fibers, proceeding presumably from the adjacent arterial wall, is seen at an early stage, especially in the subendothelial zone. In short, the phenomena are those of gradual fibrous replacement of the autograph, in which a differentiation of the individual layers of the transplant becomes less and less marked as time goes on."

Microscopic examination of a successful arterial homograft reveals a picture somewhat analogous to that found in autografts, save that the disintegration and replacement with fibrous tissue is more rapid than in autografts. Heterografts disintegrate rapidly, and early massive thrombosis is the rule. Yet in some, a channel through fibrous tissue is the result. In the use of dead preserved arteries results are more or less similar to heterotransplantation of the skin. Probably only autotransplantation of arteries in human surgery is warranted.

Hoepfner suggested the use of vein for the repair of an arterial defect, and Carrel and Guthrie first (1915) successfully employed the procedure. Although aneurysmal dilatation was expected, it was found that this did not generally occur. Microscopically the vein increased in thickness. The change was found to be caused by an increase in the connective tissue in all three layers.

Technique

The technique involves isolation and detachment of the graft and reimplantation of the graft by end-to-end anastomosis. The problem is the elimination of thrombosis in the lumen of the transplant. No errors in technique can be made if the operation is to be a successful one. Minimal trauma is necessary. The graft should be detached just before transplantation. The graft should be exactly the length of the defect. The longer the defect, the greater the chance of failure. The graft should have no lateral branches, if one can avoid it. Liquid paraffin or vaseline is employed throughout the operation for the purpose of lubricating the ends of the graft, the open artery end, and suture material. Five per cent solution of sodium citrate is recommended for flushing the interior of the graft. Any rough handling of the intima is almost certain to result in thrombosis. The poles of a vein should be reversed, so that the valves will not interfere with the circulation. Needles of very fine diameter and delicate strands of split silk especially prepared for this purpose should be used. Two or three traction sutures are passed first, and then a continuous suture is made between the three points of approximation. After the graft is sutured adequately, the surrounding tissues are drawn together about the graft.

Sometimes one can flex the limb and bring the ends of a cut artery together, making grafting unnecessary. Lateral arterial defects should not be resected. They are more efficiently taken care of by fascia or vein grafting over the defect. If the artery can be encircled with a viable flap of muscle, Isenberger's work would indicate that closure will be obtained.

The dangers of the operation should never be forgotten. Serious hemorrhage may follow, or, if a clot forms, it may be swept into other areas and cause thrombic phenomena. If this occurs to a vital center, death may be caused by the mishap. The method should be practiced just when it is the only remedial measure that is practicable. Whenever ligation of an artery would lead to necrosis of a limb or cerebral degeneration, blood vessel grafting should be considered.

A non-suture method of auto blood vessel grafting has been described by Blakemore and Lord (1945). This has been successful temporarily in about 85 per cent of the cases both experimentally and clinically. The procedure is described in Chapter X (p. 209, fig. 63).

D. The Transplantation of Organs

A vast literature has accumulated concerning organ transplantation. An accumulation of sober facts now has finally somewhat cooled the earlier enthusiasm. The whole subject of organ transplantation dates from 1854, when Schiff began his studies. He worked with the thyroid gland and found that the striking clinical signs, which follow the total removal, were delayed when the gland was transplanted to the abdominal cavity. Biedl, Knauer and others have described the work of the multitude of investigators. With our present knowledge, organ transplantation certainly has a limited applicability in surgery. Autotransplantation of such glands as the ovary, thyroid or parathyroid, clinically, has resulted in finding atrophy within a few months. After transplantation, the graft may remain partially viable for a variable period of time, but finally, as a rule, it is then replaced by fibrous tissue. In regard to the transplantation of endocrine tissue, Halsted in 1909 concluded that there must be a physiologic need for an endocrine principle in order that a graft of the gland elaborating that principle to be successful. This is known as the "law of deficiency" and has been opposed by Loeb among others.

With homotransplantation, or heterotransplantation organs have had only temporary viability. It was thought that the development of blood vessel suturing might offer some hope. However, the cause of tissue incompatability between donor and host is still unknown, and unfortunately always seems operative. Previously, we have reviewed the work of Loeb in relation to skin grafting. The same factors seem to be operative in organ transplantation. After homotransplantation, the graft remains viable only temporarily. After heterotransplantation, the disintegrative process is more rapid than after homotransplantation.

Thyroids: In 1894 von Eiselsberg attained partial success by autotransplantation of thyroid gland into the abdominal wall. Three months later microscopically the outer layer of cells stained well and the acini were occupied by colloid. Later Cristiani and others began heterotransplantation of thyroid (using sheep's glands), and Kocher tried homotransplantation. The results in the first case were nil and in the latter case were temporary. Cristiani thought that he proved that thyroid gland may be autotransplanted. The recent work of Stone and Owings is of interest. They believe that they successfully homotransplanted thyroid gland, after growing the gland of the donor in the serum of the recipient by tissue culture methods for a period of time before transplantation. No further follow-up reports have occurred since their original paper. Most men question whether autotransplants have ever been made to grow permanently under any set of circumstances. Loeb, however, stated: "It is possible in inbred families to transplant successfully as many as four lobes of the thyroid gland from one individual to another one, possessing its own thyroid gland and thus proving that a deficiency in thyroid hormone is not required for successful transplantation. Ingle and Craig (1939) observing thyroid transplants in partially and completely thyroidectomized rats agreed that the

tissue could be successfully transplanted but stated: "Our studies tend to substantiate the view that the transplanted thyroid gland grows rapidly and shows microscopic evidence of increased cellular activity when a definite state of thyroid deficiency exists.

Ovary: Knauer performed the first experimental studies and demonstrated the transient viability of autografts of ovary. In an occasional case, pregnancy is said to have occurred after the transplantation of ovarian tissue. Guthrie experimented in hens and concluded that autografts functioned for about a year and then ceased. Robertson using agouti strain and $101X^{Y}$ yellow mice performed a bilateral oophorectomy on the agouti mice. Following this operation he transplanted the ovaries of the yellow mice to the host agouti. In 18 out of 38 cases yellow mice were produced after the host agouti was bred with a male of the agouti strain. His work supported Halsted's theory of endocrine deficiency. Neuhof, however, in 1923 stated that, after careful analysis, "we are unable to discover a single case in the literature of successful autotransplantation or homotransplantation of the ovary in the human being, the proof of which is incontrovertible."

There is, however, considerable evidence, which would tend to suggest the persistence of function of ovarian autografts for some period of time, at least. Tuffier, Bell and many others have had a considerable experience in autografting of ovarian tissue in the human. Martin analyzed the literature admirably up to 1921. Bell up to 1925 had an experience of 200 ovarian autografts, when he published his results. Bell crosscut the ovaries into small bits and transplanted the fragments into the rectus muscle. After a period of quiescence of one to eight months, in about 80 per cent, functional results appeared. By functional results he meant that the symptoms of the menopause were abolished, and in those patients where a portion of the uterus was preserved (Bell-Beuttner procedure), menstruation reappeared in 66 per cent. A few of his patients menstruated normally after seven years.

Kidney: The grafting of kidney involves the grafting of the whole organ, and depends first upon blood vessel anastomosis. Although Ullman made the first efforts to graft a kidney, Carrel and Guthrie, in 1905, first demonstrated beyond question that successful autotransplantation of the kidney was possible. They transplanted the entire renal system. Immediate success was obtained often, and absolute sucess was obtained in one instance. The dog lived two years. Zaaijer has reported a dog alive and well six years after autotransplantation of a solitary kidney. The procedure is of scientific interest, but is of no practical importance.

Decastello experimented with homotransplantation of the kidney, and Ullman with heterotransplantation. There is not a single instance of survival of the animal with the transplanted organ as the sole kidney. In a few instances some evidence of transient viability was shown. The usual report is death of the graft and necrosis. Heterografting has been tried in the human (Ullman, 1902, and Jaboulay, 1906), but homografting has not been tried in the human being.

Parathyroids: The first experiments in transplanting the parathyroids alone were performed by Generali and Vassale with questionable results. Cristiani (1905) thought he demonstrated the feasibility of autotransplantation of the parathyroid gland, and in 1892 von Eiselsberg obtained aid in working out the physiological significance of the parathyroid gland by autoplastic experiments.

Transiently successful efforts of homotransplantation of the parathyroids as judged by maintenance of function and lack of tetany have been reported by Pool and Halsted. Halsted reported that in 615 of the cases in which a deficiency of greater than ½ had been created, autotransplantation of the parathyroid gland in dogs had been successful. Isotransplantation had been uniformly unsuccessful. However, upon analysis of their studies it may be said that the reports have been made too soon following transplantation to give a satisfactory estimate of the effects of the procedure.

Testicle: Berthold initiated the experimental work on transplantation of the testicles. The

generative function has never been obtained by testicular transplantation. Autotransplantation, it is said, has resulted in retention of the male characteristics. It is probable that the skeptical interpretation should be placed upon this statement. Lespinasse did a homotransplantation of a testicle, and reported that the man had a return of potency, which was lacking previously, and he maintained this function for five years. Such a report is questionable, and would not warrant the clinical application of homotransplantation of the testicle.

Adrenal Gland: The first adrenal transplantation was made in 1887 by Canalis. Boinet made the first systematic study of autotransplantation of the adrenal gland. Prompt death of the autotransplants occurred in each instance. Higgins and Ingle (1939) reported autotransplants of the adrenal gland in rats to be successful, as judged histologically, if a deficiency state had been set up by removing both adrenal glands. The cytological studies have not been reported. Williams, transplanting grafts of adrenal cortex to transparent chambers installed in the ears of rabbits found the tissue remained viable. When he transplanted the tissue of new born rats to the brain cortex of adult animals he found that the adrenal gland became completely differentiated and provided adequate functional replacement in bilaterally adrenalectomized animals during a period of at least 274 days. Adrenal transplantation is not likely to be successful because of close association of the gland with the central nervous mechanism. DeDominici presented evidence that the function of the adrenal is lost when the nerve connections of the organ are severed. This he found was true, despite the fact that microscopic examination of the gland manifested no abnormality.

Thymus and Spleen: There is no clinical indication, according to our present knowledge of the physiological function, for transplantation of the thymus gland. The same may be said of the spleen.

Pancreas: Minkowski in 1892 transplanted sections of the pancreas with the object of supplying its internal secretion to the body. His experiment is often quoted, but the interval between removal of the remaining pancreas and of the graft was so short that the experiment does not prove more than absorption from a graft, which was degenerating. Transient viability of autografts may occur. Homotransplantation of the pancreas has not been carried out successfully. Thus, there are, at present, no clinical possibilities for the grafting of the pancreas.

Hypophysis: Crowe, Cushing and Homans demonstrated transient viability of autografts in a small proportion of their experiments, involving autotransplantation of the whole of the hypophysis. Homotransplantation or heterotransplantation — the only methods that could be of practical clinical value — do not warrant serious consideration at present.

General Comment

Organ transplantation in toto of the autotype, from the nature of the procedure, would have small clinical applicability, even if it were possible to maintain the blood supply to the organ as a working procedure. The procedure depends upon a blood vessel anastomosis, which as yet can hardly be called a practical procedure. The question of transplanting minute pieces of the various glands of internal secretion depends upon a different method of obtaining a blood supply, and one which may conceivably be possible and practical in the case of autotransplantation. This limits the practicability of the procedure to a considerable extent. Homotransplantation and heterotransplantation, however, face the fundamental law of cellular antagonism, as outlined by Loeb. We have previously alluded to this work several times.

E. Keratoplasty

Sporadically, for many years experimentation has gone on as to the practicality of corneal grafts. All too often extensive corneal ulceration leaves as its aftermath a useless eye. Therefore, if corneal grafts would take and leave a transparent eye, it would be a considerable boon to many sightless individuals. Up until recently all attempts were un-

successful, but Elschnig of Prague (1923-1930) has thrown a somewhat different light on the matter. The recent workers in the field have been Wood (1914), Walker (1917), Ascher (1922), Kerbut (1922), Forster (1923), Elschnig and Gradle (1923) and Castroviejo (1932).

Total keratoplasty is quite impractical. The usefulness of superficial lamellar transplants is very limited. If the opacity does not extend deeply into the corneal tissues, the lesion is usually circumscribed in extent. More hope for visual improvement lies in the comparatively simple procedure of iridectomy. Penetrating circumscribed keratoplasty is the most widely applicable procedure. A portion of the cornea is removed and replaced by transparent corneal tissue. In 1877 Hippel excised a disc of the affected cornea with a trephine, and obtained a similar transplant of the same size and shape. He kept it in place by eyelid pressure. Zirm in 1906 suggested that, instead of leaving the transplant loose, to hold it in place by means of a bridged double suture extending over it from the conjunctival limbus on either side. In 1930 Elschnig had 174 patients. He reported 22 per cent successes with 73 per cent of these in cases of interstitial keratosis, and that a visual result of 6/6 from an initial vision of appreciation of hand movement only is possible.

Ortin (1914-16-31) experimenting on rabbits, indicated that autotransplants do "take" and do not become opaque. In homotransplants there was question. In one rabbit three quarters of the transplant is said to have remained clear, but the other quarter did not. The heterotransplants all became opaque.

As with other grafts, observers do not agree on the ultimate fate of the graft. Salzer (1900-21) and Bonnefon (1918) considered that the transplant eventually disappeared, serving as a framework within which the tissue of the host gradually proliferated. Ortin (1914-31), Ascher (1919-22) and Sommer (1925) maintain that the graft retains its individuality. The sections of Thomas (1932) and Castroviejo (1934) would indicate that the latter is true. Paton reported 100 cases stating that in nearly all cases sight was improved. In three cases eyes were lost and in four cases serious post-operative complications developed and in only two cases was a vision of 20/30 obtained. The average improvement was from the ability to count fingers at two feet to visual acuity 20/200.

Duke-Elder, in summarizing the experience of the various workers, reached the following conclusions: "Penetrating circumscribed keratoplasty is the method of choice using transplants of the same species. Although autoplasty should give better results, it is inapplicable." Elschnig states that his experience indicates that the graft may be taken from any donor.

It may be pointed out that the mere fact that some increase of vision is noted after corneal homoplastic transplantation, does not tell one whether or not the transplant was or was not eventually replaced by a less dense tissue. It is possible that observations on this point may not be accurate. Corneal tissue is a peculiar tissue and has no blood supply. If a homograft remains in situ in its original cellular state, it must be a unique tissue. The fact that heteroplastic grafts do not "take" or become opaque more quickly than homoplastic grafts, and that homoplastic grafts show a quicker change towards opacity than autografts suggest that the organismal differentials are still active in a manner similar to that of other tissue, when grafting is attempted or when ultimate viability is considered.

Transplantation of Lens of Eye

The lens of the eye shows organ specificity, according to Loeb, but its species specificity is not highly developed. Fleisher carried out a series of auto-, homo- and heterotransplantations in animals. Homo reactions against the transplant were lacking. There was a distinct hetero reaction.

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